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Forest Regeneration in the ESSFa Subzone: A Problem Analysis

by
Gordon Butt

Madrone Consultants Ltd.
108-225 Canada Avenue
Duncan, B.C.
V9L 1T6

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Forestry Canada
Pacific Forestry Centre
506 West Burnside Road
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(604) 388-0600

or

B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(604) 387-6719

EXECUTIVE SUMMARY

An historical analysis of forest regeneration in the ESSFa subzone in the Cranbrook and Invermere Forest Districts was carried out to determine the reasons for the excessive amount of NSR (not satisfactorily restocked) land, and to identify ecological and silvicultural problems affecting regeneration success.

Information was gathered primarily from on-site inspections of 65 sampling sites on 46 openings. They had been created either by logging or wildfire between 1970 and 1979. At each sampling site, information was collected on all relevant site factors, as well as on competing vegetation and natural regeneration. Regeneration performance, including both conifer height and stocking, was also measured. This information was augmented by a reconstruction of the treatment history of each sampled site, using opening files located in the Cranbrook and Invermere Forest Districts.

An analysis of historical information gleaned from one-time reports generated by the Silviculture Branch, Victoria, showed that between 1961 and 1985 about 58 000 ha were denuded in the ESSFa subzone in the Cranbrook, Invermere, and Golden Forest Districts. Of that area, more than 31 000 ha are now classed as NSR (53.5%). If older denudation is included, the NSR land is even higher. Between 1961 and 1985, nearly two-thirds, or just under 20 000 ha, of NSR land was untreated. The extent of forest land that was denuded but not subsequently treated is an important contributing factor to the NSR problem in the ESSFa subzone.

Analysis of data collected from on-site opening assessment yielded the following conclusions:

Moisture regime and site impact strongly influenced regeneration performance. The best height growth was observed on mesic and mesic-subhygric sites which had sustained a relatively high site impact. These results indicated that excellent height growth, as well as survival, are possible in the ESSFa. This potential was seldom realized, largely because of the failure to prescribe or achieve impacts appropriate to the site.

Apparently, poor regeneration performance on steep north aspects and on subhygric sites was caused by adverse environmental factors and competing vegetation. These conditions can be mitigated by achieving high (but not excessive) site impacts. North aspects averaged much lower impacts than other sites. Poor height growth in subhygric sites was attributed to low soil temperature, periodic moisture excess, competing vegetation, and repeated cold injury. Plantations on lower slopes and valley bottoms characteristically exhibited leader die-back and poor form, particularly on low impact sites.

Regeneration performance diminished above 1800 m. This was attributed to limitations in growing season length and average daytime temperatures. Survival was affected more consistently than height growth. Height growth in sampled plantations increased with increasing elevation between 1500 and 1800 m, then diminished above this elevation. Plantations at lower elevations (< 1700 m) appeared to suffer a greater incidence of cold injury than at higher elevations (> 1700 m).

Competing vegetation contributed to poor regeneration performance on a number of sampled sites, but was not considered the most serious constraint to performance. Average total vegetation cover was 35%. Four common vegetation complexes were identified. These were fireweed, false azalea, grass, and alder. Analysis of competing vegetation and regeneration performance showed that at high cover values the fireweed and false azalea complexes had a detrimental effect on both height growth and survival. Alder was observed to pose a serious threat to regeneration on a small number of sites, but this was not confirmed in the analysis. Alder showed low average cover values and its spatial distribution in disturbed areas is highly irregular. The occurrence of fireweed, false azalea and alder complexes could be predicted on the basis of moisture regime and site impact.

Natural regeneration consisted mostly of Engelmann spruce and subalpine fir. Post-logging recruitment of spruce and subalpine fir contributed significantly to total stocking, but height growth was frequently much slower than for planted seedlings. Reliance on post-logging recruitment of spruce and subalpine fir cannot be recommended unless it is reasonable to add 20-30 years onto the rotation age. Reliance on regeneration present at the time of logging is appropriate on a site-specific basis, but has often been incorrectly prescribed. Management for lodgepole pine natural regeneration on appropriate sites appears to be relatively successful.

Preparation delay did not emerge in this analysis as an important factor influencing regeneration performance. Planting delays greater than 3 years were associated with reduced height growth but not with survival. This reduction in height growth was most pronounced on mesic and wetter sites. Planting delay was relatively unimportant on drier sites.

Poor species selection was responsible for poor performance in at least eight sites sampled. These involved the prescription of spruce for drier and very highly impacted sites. Pine would have been preferable in each site.

The 10 best plantations (exhibiting excellent height growth and survival) were identified and tabulated. All 10 were planted following burning, either prescribed (8 cases) or wildfire (2 cases). All were planted within 2 years of site treatment. A higher proportion of pine plantations were successful than were spruce. All successful spruce plantations were established on mesic or "nearly mesic" sites following high impacts. The successful pine plantations, on the other hand, were established on somewhat drier sites following medium impacts.

The high historical failure rate of untreated sites has two implications for modern forestry in the ESSFa. First, it indicates that appropriate site preparation, by prescribed fire or mechanical means, is essential for successful regeneration on mesic and wetter sites. The only exceptions to this are where adequate cone distribution will allow pine restocking or where adequate existing regeneration is of suitable density and quality to form the next crop. It is recommended that sites requiring treatment for successful regeneration be identified at the pre-harvest stage. If treatment on these sites is not feasible, they should either be excluded from harvesting or managed for existing regeneration. In the latter case, the stand should contain a sufficient density of quality residuals and advance regeneration. Relaxation of local minimum stocking standards should be considered. Secondly, rehabilitation of untreated NSR land will present a challenge. It will require a close examination of the cost and benefit of trying to undo past mistakes. Increased investment in current silviculture is far more cost effective than allowing these backlog stands to develop again.

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1 INTRODUCTION

Forest regeneration in the ESSFa subzone in the Nelson Forest Region has frequently failed to meet expectations. Between 1961 and 1985, more than 31 000 ha of forest land were denuded but not satisfactorily restocked (NSR). This accounts for about 53% of all land denuded, either by logging or wildfire, during that period.

In fact, 31 500 ha NSR clearly indicates that something is wrong. Could the ESSFa subzone have a particularly inhospitable environment? Were silvicultural treatments inappropriate, or poorly executed?

In an attempt to discover the causes of this failure rate, historical success and failure in regeneration were examined. An earlier study (Butt 1987) was based entirely on silvicultural opening files for ESSFa openings containing NSR land and on interviews with silviculture staff. Thus, the conclusions and hypotheses generated were highly tentative. This report examines some of those hypotheses in more detail.

The objectives of this project were to:

1. document the distribution and ecological dynamics of major brush types in the ESSFa;
2. identify successful and unsuccessful site-treatment combinations;
3. suggest changes in silvicultural recommendations for regenerating ESSFa sites, where necessary; and
4. develop recommendations for further research.

In contrast to the earlier review of NSR openings, this study relied heavily on field assessments of openings. Sources of information were:

1. detailed objective assessment of 65 sites on 46 openings distributed throughout the ESSFa subzone in the Cranbrook and Invermere Forest Districts;
2. subjective assessment of these and other sites as examples of regeneration difficulties or success;
3. interviews with silviculture staff;
4. analysis of historical one-time reports, generated by Silviculture Branch, Victoria; and
5. review of pertinent literature.

This is an historical study; it attempts to learn from what has been done in the past. The methodology involved reconstructing the silvicultural history of 65 strata in 46 openings and assessing ecological conditions. A large quantity of data was amassed. Using computer-aided data manipulation we were able to identify certain trends and to pinpoint ecological and silvicultural factors associated with regeneration success and failure.

Historical studies have certain advantages over process-oriented studies. They summarize years of experience and can provide results almost immediately. They allow us to learn from the mistakes of the past and to benefit from past successes. They also have certain disadvantages. Accurate reconstruction of events and conditions is not always possible. Details about site preparation were commonly lacking from history records. In some cases the cause of regeneration failure was apparently not related to site or treatment factors and could not be deduced from available information. In some openings, weather conditions during the first season following outplanting was probably responsible for failure. Finally, historical studies focus on treatments applied in the past. The impacts of new or modified silvicultural treatments are not directly assessed in this project.

A dependence on sorting of data to reveal trends and associations also has limitations. This is a "black box" approach which may obscure as much as it reveals. Accordingly, observations of regeneration performance gained over the course of the field sampling exercise form an important part of the results of this project.

2 GEOGRAPHICAL BACKGROUND

The Engelmann spruce-subalpine fir (ESSF) zone occupies higher elevation sites throughout British Columbia. It is subalpine in nature, with severe winters, moderate to high snowfall and relatively short growing seasons. In the southern Interior, the ESSF is probably the most difficult biogeoclimatic zone to regenerate.

In the extreme southeast of the province, the ESSFa ("dry, southern, cordilleran, forested") subzone occupies sites between about 1500 and 2100 m in the Purcell and Rocky Mountains (Figure 1). At its lower elevational limits it meets the Montane Spruce Zone, and merges into the parkland (ESSFap) subzone above about 2100 m (Utzig *et al.* 1986).

The ESSFa forests are located on the slopes and floors of mountain valleys. Soils on steep valley slopes may be shallow and rocky. Valley floor sites commonly form a mosaic of productive forest and open fens. Physiography frequently dictates access planning and cutblock lay-out.

Our limited data suggest that although not as dry as the ESSF in the Okanagan and Kamloops areas (Mount Kobau and Mount Lolo, respectively), the ESSFa is probably the driest ESSF unit in the Nelson Forest Region and one of the driest in the province. Growing season precipitation (May to September rainfall) in the two ESSFa stations in Table 1 is about one-half to two-thirds that of Glacier National Park in the ESSFc subzone. Significantly, total snowfall is much less in the ESSFa subzone, compared to areas of similar elevation further north. Taking these two factors into account, it is probably safe to say that moisture stress felt by seedlings is a more serious factor in the ESSFa subzone than in other ESSF subzones in the Nelson Region.

TABLE 1. Climatic characteristics of the ESSF zone in the southern interior

Station	Elevation (m)	Annual snowfall (cm)	Rain (May-Sept) (mm)	Annual temperature (°C)	Temperature (May-Sept)	Days of frost
Fording River	1702	425	257	1.5	10.7	40
Natal Harmer	1890	662	201	0.3	9.1	38
Glacier National Park	2169	1975	415	0.2	7.9	34
Mount Kobau	1862	385	153	1.1	8.8	34
Mount Lolo	1737	246	221	1.1	9.2	34

Comparison of other climatic parameters suggests that the ESSFa does not stand out as a particularly harsh environment (Table 1). In addition to being drier, the ESSFa has somewhat warmer summer temperatures than further north. Incidence of frost in the growing season, extreme low temperature, mean January temperature, and the number of months in which mean temperature is below freezing are all well within the mean for southern interior ESSF units.

Figures 2 and 3 show the annual distribution of average maximum, mean and minimum for Fording River Cominco and Natal Harmer Ridge stations (the only two AES stations in the ESSFa subzone). These figures indicate that mean minimum temperatures exceed freezing during mid- to late May, then fall again below freezing in late September at these two sites. Between these dates mean minimum temperatures are above freezing, but at any time, individual nighttime temperatures may dip below zero. Figure 4 shows the average incidence of frost (based on 30-year normals). In no month does this incidence drop to zero.

The chance of nighttime frost is significant in terms of the silvicultural implications. Frost may destroy or seriously injure plantations if it occurs before sufficient hardening-off has been achieved. Figure 4 shows that, for both stations, the probability of frost increases dramatically after mid-August.

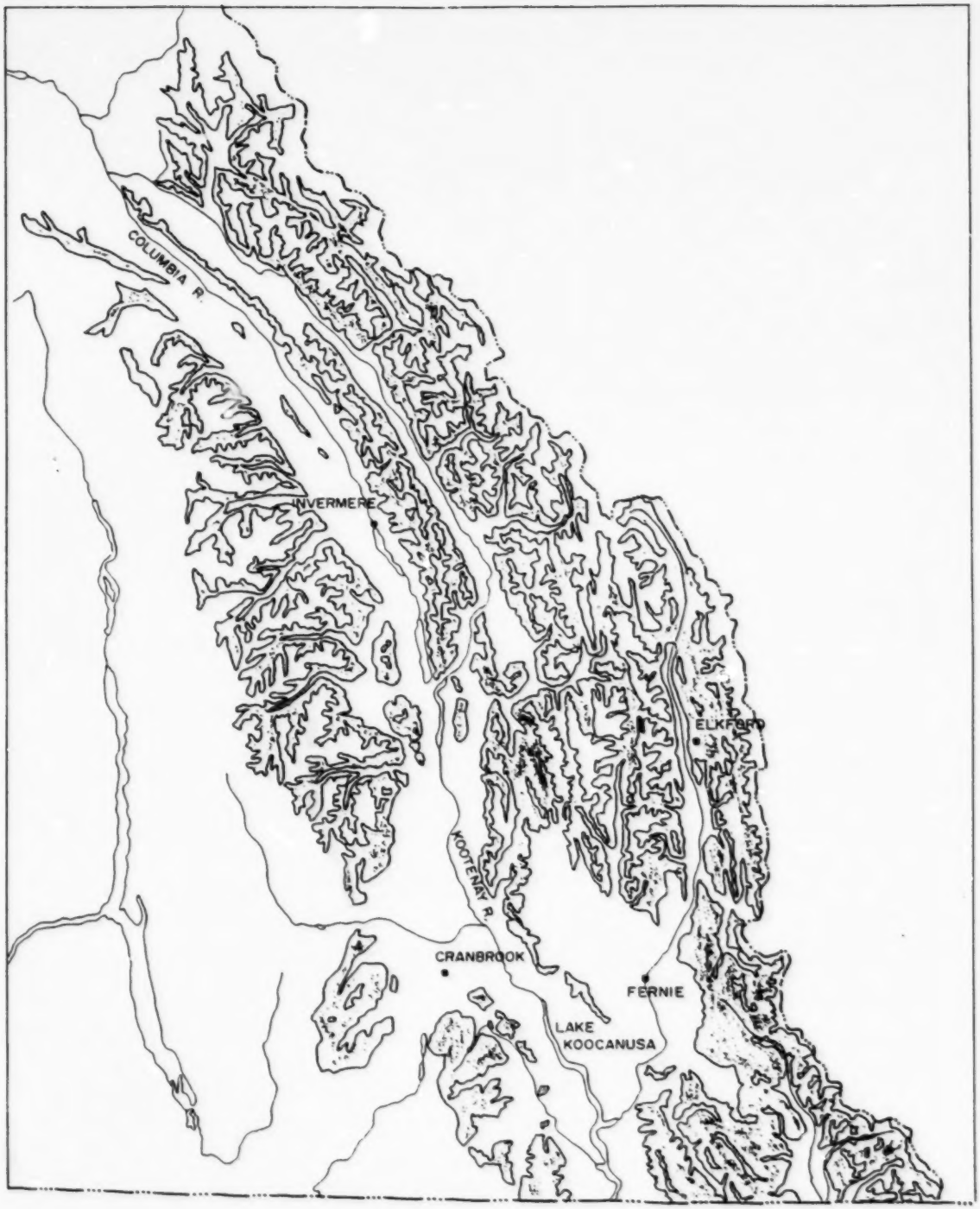


FIGURE 1. Location of ESSFa subzone.

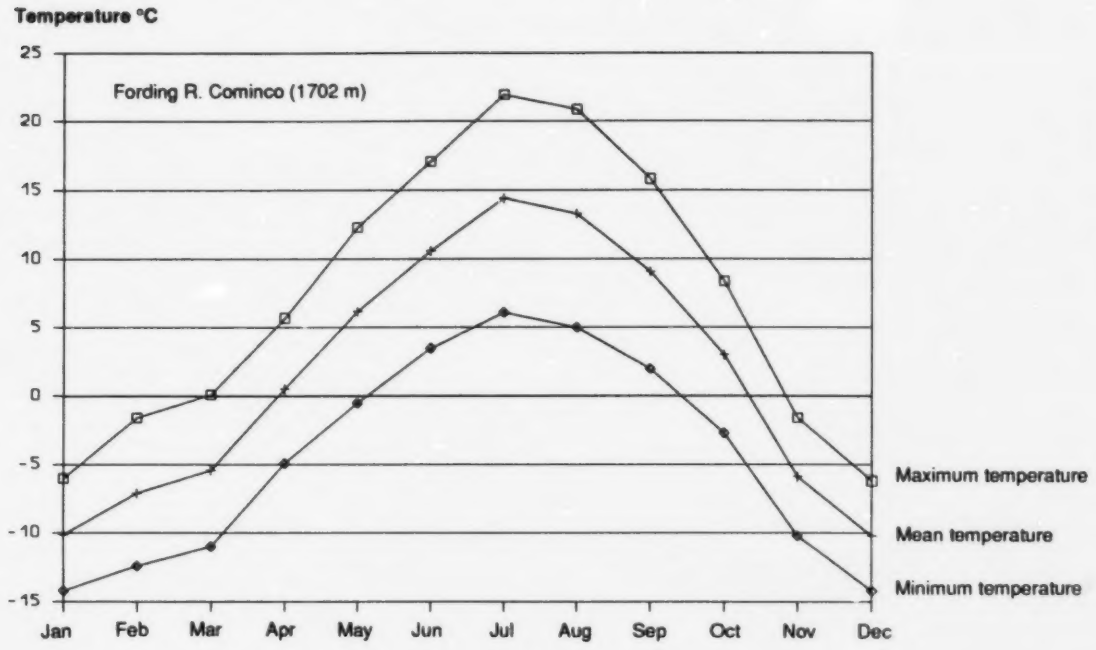


FIGURE 2. Temperature regime: Fording River Cominco.

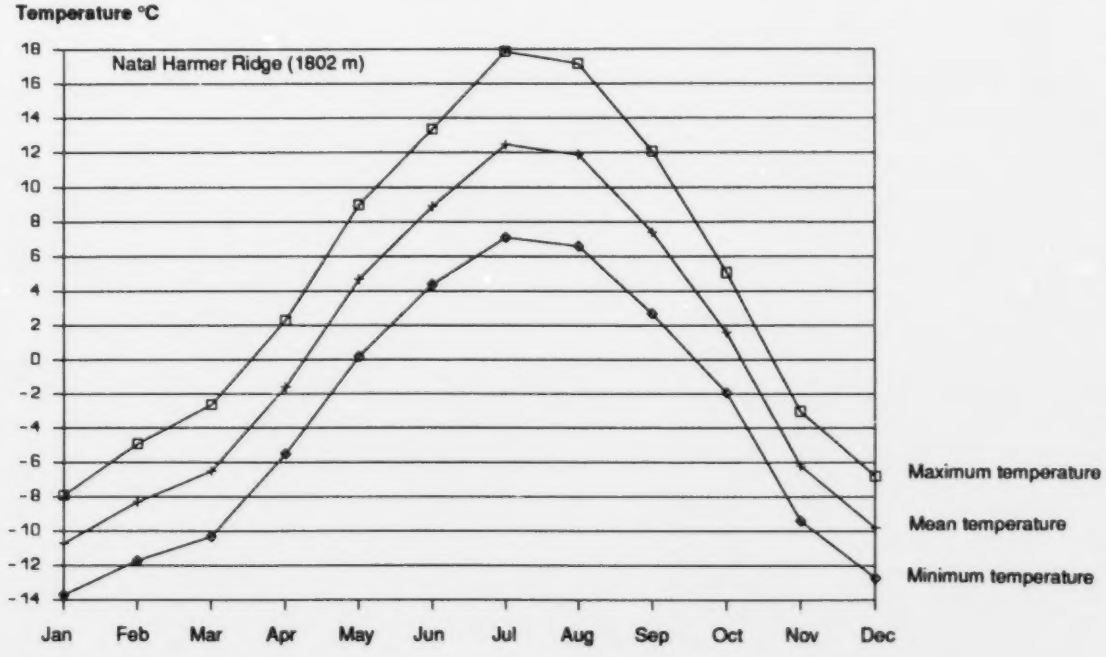


FIGURE 3. Temperature regime: Natal Harmer Ridge.

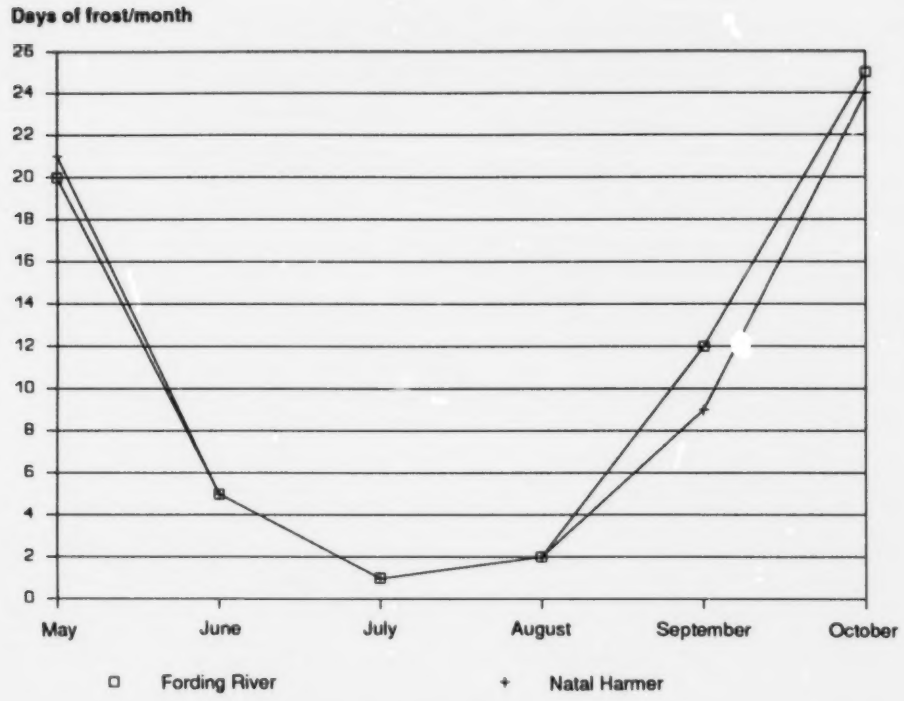


FIGURE 4. Days of frost: Fording River Cominco.

The incidence of frost is highly sensitive to slope position and the nature of the surface. In the mountains, valley bottoms and lower slopes may experience frost more frequently than sites at higher elevations, due to the ponding of cold air. For example, the incidence of frost at Fording River, located in a valley bottom, is higher in September than it is at Natal Harmer Ridge, located on a ridge nearly 200 m higher (Figure 4). Although mean summer daytime temperatures at Fording are higher, nighttime temperatures are consistently lower. In similar forests in southeast Wyoming, DeLucia and Smith (1987) found that while daytime temperatures decreased with increasing elevation, nighttime minimum temperatures actually increased with elevation.

Another environmental risk to establishing seedlings is high surface temperatures. In the mountains, the effect of aspect exaggerates diurnal temperature fluctuations; afternoon temperatures on south-facing slopes may be high enough to promote moisture and possibly thermal stress in a seedling. For example, in western Montana, Shearer (1967) recorded surface temperatures up to 65°C on south and west aspects.

3 SILVICULTURAL BACKGROUND: LOGGING AND SILVICULTURAL TRENDS (1961-1985)

This chapter discusses trends in logging and site treatments between 1961 and 1985. Information was gathered from reports issued from the History Record System (HRS) of the Silviculture Branch, Victoria; from interviews with experienced individuals; and from selected documents.

These data have distinct limitations. Their accuracy is highly variable, depending on the objectives and care of Forest Service staff over the survey period. Definitions have changed during this period. Furthermore, history data provide a blanket overview, without allowing a detailed understanding of the reasons for certain trends. Differences in the amount of NSR between Forest Districts may be due to ecological differences, administrative differences or differences in silvicultural effort. We will never know from history data alone. Thus, caution is needed in interpreting the results from this chapter.

3.1 Denudation

Figure 5 shows the total denuded area by district in each 5-year period between 1961 and 1985. The total area denuded was 58 429 ha. The bulk of this was in the Cranbrook and Invermere Forest Districts. Between 1965 and 1975, denudation in the Cranbrook District surged ahead, to about 1600 ha per year. This reflects salvage logging of stands affected by spruce bark beetle. A similar but less striking peak was observed in the Invermere District, due largely to salvage logging of stands damaged by mountain pine beetle. Over the entire survey period relatively little denudation occurred in the Golden District, reflecting the small extent of ESSFa there.

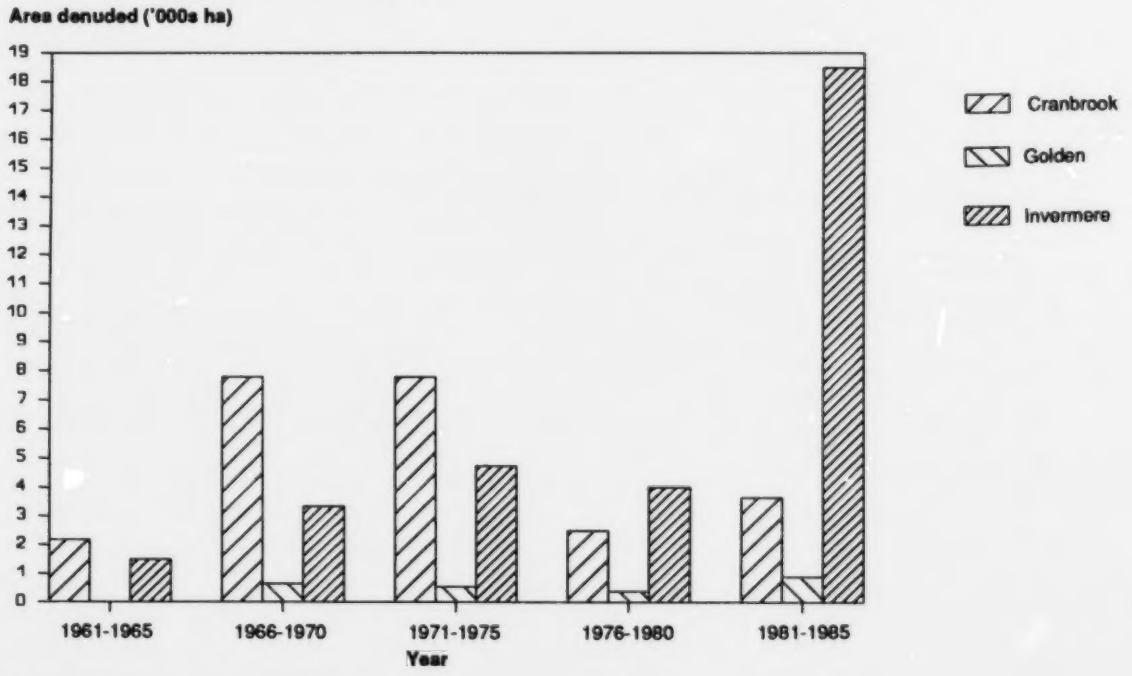


FIGURE 5. Total denuded area.

More than 18 000 ha were denuded in the period between 1981 and 1985 in the Invermere District, representing the largest single contribution to denuded land in the entire survey period, and accounting for nearly one-third of the total denuded land area. The Ram Fire and others in 1985 were responsible for this sudden contribution. Its impact is felt in all following historical summaries. If the 1985 wildfires are discounted, the rate of denudation has averaged about 2 200 ha per year in the ESSFa in the 25-year period ending in 1985.

3.2 Denudation Type

Except for the period 1981-1985, most denudation was accomplished by logging (Figure 6). Prior to that period wildfire accounted for between about 6 and 20% of the total land area denuded, with logging accounting for the rest. The Ram Fire contributed 16 711 ha to denuded land area in the ESSFa, according to history records. Prior to the Ram Fire the proportion of denuded land created by wildfire varied substantially in each 5-year period, but overall was similar in both districts.

3.3 Total NSR Area

A total of 31 271 ha of forest land is classified as NSR in the ESSFa subzone. About two-thirds of this total is located in the Invermere Forest District. Figure 7 shows the distribution of total NSR land by

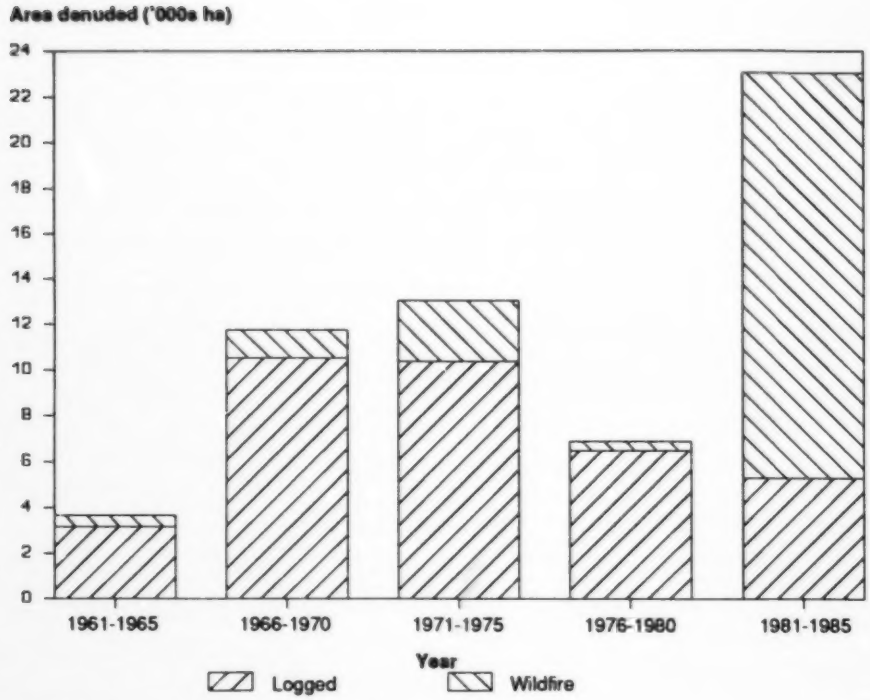


FIGURE 6. Denudation from logging and wildfire.

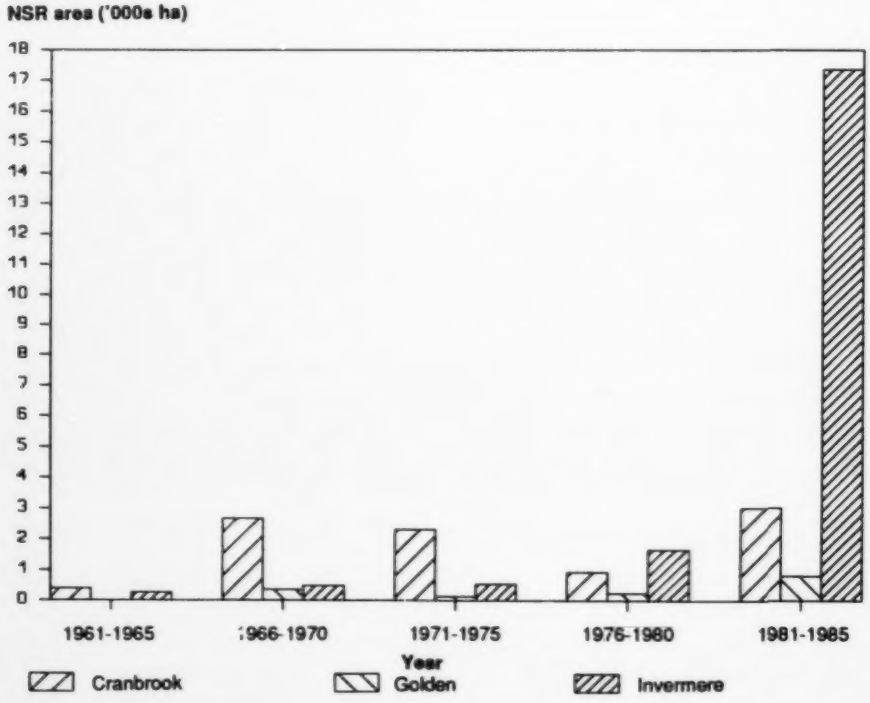


FIGURE 7. Total NSR area.

5-year period for each district. The 1985 wildfires contributed about 50% of the total NSR. Much of this NSR would have been classed as current, rather than backlog, at the time the historical report was generated (January 1988). Prior to 1985, more NSR land was present in the Cranbrook District than in Invermere.

3.4 Percent NSR Land

Figure 8 shows the proportion of total denuded area which is classed as NSR. It suggests that the percentage of NSR land is actually increasing with time. In fact, this trend reflects two factors:

1. the tendency of older openings to restock naturally over time; and
2. the fact that NSR estimates for the recent period (1981-1985) include current with backlog NSR.

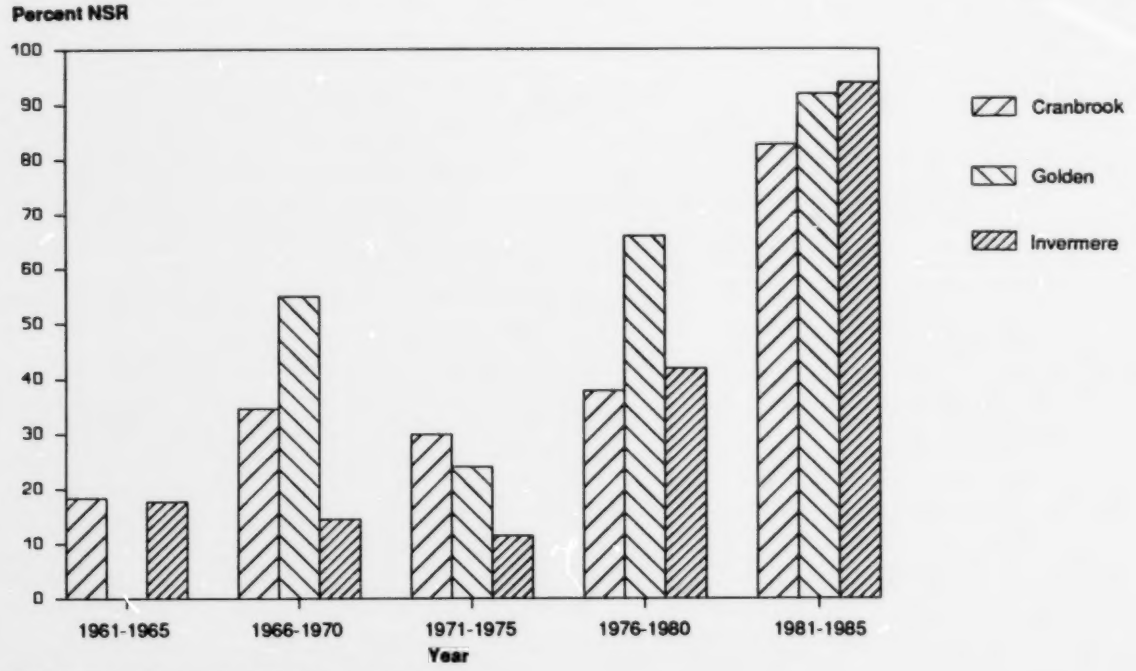


FIGURE 8. Percent NSR land by district.

A number of other features can be observed in Figure 8. First, although the total area denuded in Golden has always been small, the percent NSR land has been relatively high. In fact, the percent NSR land in that district was substantially higher than for the other two districts in the periods 1965-1970 and 1975-1980. Secondly, the percent NSR land for all districts during the period 1971 to 1975 was relatively low. At this time, salvage logging was active in both Cranbrook and Invermere districts. The percent NSR land in Invermere was only 11.5%, at a time when pine salvage logging was the main form of denudation taking place. This suggests that pine sites are relatively easy to regenerate, compared to spruce or spruce-balsam sites.

3.5 Site Treatments

Figure 9 shows the breakdown of total denuded area in the ESSFa by treatment type. The groupings on the horizontal axis are broadcast burning (BBROAD); windrowing or piling (MWIND); other mechanical treatments, such as chain-dragging (M-OTHER); and no treatment (NONE). The extent of denuded land experiencing no treatment in this picture is dramatic. The revealing point about this diagram is the large extent of untreated area and the relative paucity of treated land. The area of untreated land in the

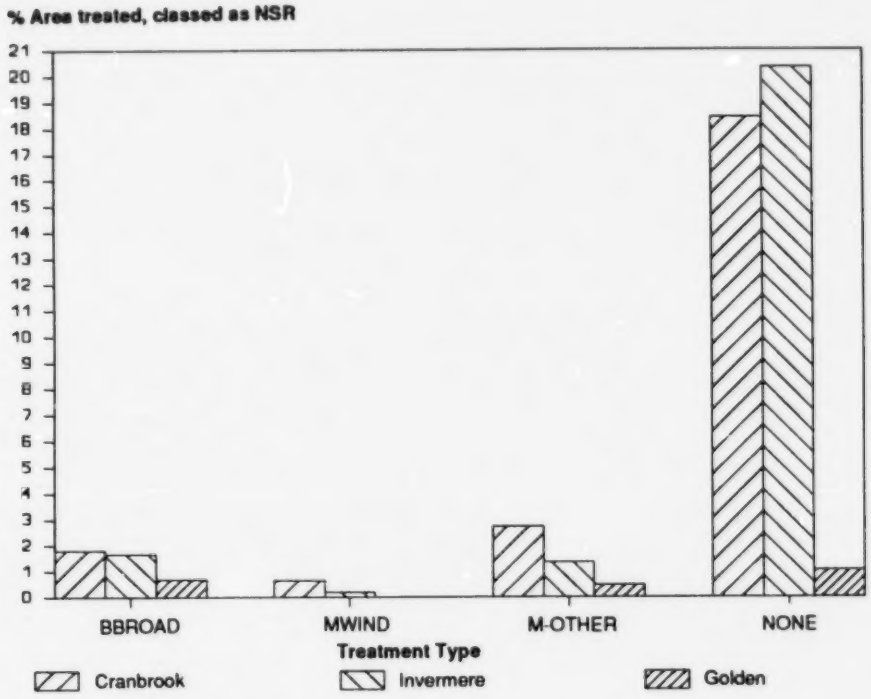


FIGURE 9. Denuded area by treatment.

Invermere district is strongly influenced by the Ram Fire. However, a total of 18 418 ha of forest land in the Cranbrook district were untreated as well. Less than 2000 ha have been broadcast burned in each of the Cranbrook and Invermere districts. Over the survey period, the use of broadcast burning dropped substantially after 1975. No broadcast burning was carried out in the Cranbrook Forest District between 1981 and 1985.

Windrowing has been applied to fewer than 1000 ha in the entire ESSFa subzone. This small area reflects the terrain limitations to mechanical treatment in this rugged area. Other mechanical treatments have been more extensively used, the main one being chain-dragging for natural regeneration on lodgepole pine sites. Chain dragging has been used on more than 2000 ha in the Cranbrook district.

Figure 10 shows the percent NSR land by treatment type. This graph suggests that broadcast burning and windrowing are associated with the lowest NSR percentages. According to history record information, only about 30% of denuded area treated with prescribed fire has been classed as NSR in the Invermere district. This compares to about 60% NSR for "no treatment." Note that Golden has the highest percent NSR land in three out of four categories. Since the total area tabulated in this district is small, this is not very significant. In the period 1961-1985, 19 819 ha of denuded but untreated land are classed as NSR. From this analysis, it appears that lack of treatment is an important contributing factor in the NSR problem.

4 METHODS

4.1 Opening Selection

Assessment of the ecological and silvicultural conditions of 65 sites in 46 openings was carried out in the summer of 1987. The breakdown of these selected sites by Forest District, range, logging method, and regeneration method is shown in Table 2.

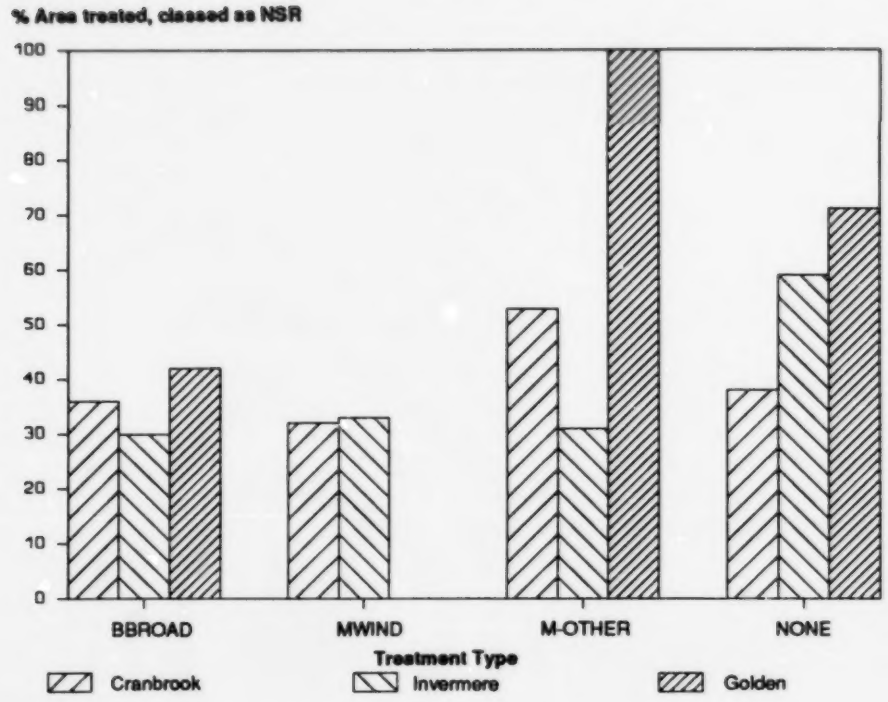


FIGURE 10. Percent NSR land by treatment.

TABLE 2. Number of plots sampled by district

	Cranbrook	Invermere	Total
Total number of sites	37	28	65
Rockies	29	14	43
Purcells	8	14	22
Clearcut	36	26	62
Broadcast burned	19	16	35
Planted	27	19	46
Planted – spruce	23	12	35
Planted – pine	4	4	8

Openings for assessment were chosen after consultation with district staff. Criteria were: 1) accessibility; 2) establishment age of at least 5 years; 3) even distribution geographically, that is, by Forest District, mountain range, elevation, etc.; and 4) even distribution by treatment and regeneration method.

Approximately 50% of all sites were entirely or partly NSR. Most openings selected were clearcut, because modern logging practices tend to avoid partial cutting unless wildlife constraints apply.

Sampling sites were concentrated into one of nine drainages. These were as follows:

Drainage	District	Mountain Range
1. Cabin	Cranbrook	Rockies
2. Harvey	Cranbrook	Rockies
3. Quinn	Cranbrook	Rockies
4. Bloom Creek	Cranbrook	Purcells
5. White River	Invermere	Rockies
6. Lussier	Invermere	Rockies
7. Horsethief	Invermere	Purcells
8. Jumbo Creek	Invermere	Purcells
9. Bugaboo Creek	Invermere	Purcells

Within each drainage, sampling was carried out on sites over a range of ecosystems, aspects, elevations, site treatments, etc.

4.2 Opening Reconstruction

The historical file for each opening selected for field assessment was examined. Relevant data pertaining to site treatment, including disturbance date, logging method and season, site preparation and date, planting stock and conditions, were recorded. Scanty information on numerous openings limited the quality of historical reconstruction. In particular, early accounts of site preparation were missing. Frequently, descriptions of stock type and planting conditions were not available. The quality of information was usually superior on recent (post-1980) openings.

4.3 Field Assessment

Each opening selected was stratified into areas which were uniform with respect to moisture regime, aspect, site treatment, logging method and other factors. Sampling sites were located within selected strata. At each sampling site a transect line was randomly located. Five fixed-radius ($r = 2.54$ m) plots were established at 10-m spacings along the transect line. The total area within the five circular plots was 100 m^2.

Within the circular plots, height and total number of all crop trees were recorded, along with estimated cover and height of major competing species.

At each sampling site, numerous site attributes were measured or observed. These attributes included elevation; aspect; slope gradient and position; moisture and nutrient regime; soil type; texture; depth of rooting; humus form; and depth of duff remaining. In addition, the amount and distribution of slash and regenerating species were recorded.

Subjective remarks were organized around the following topics:

1. Site Impact: A rating of site impact ranging from Very Low to Very High was ascribed to every site. This rating was based on depth of duff remaining, charring of slash and stumps, distribution of fine fuels and exposure of mineral soil. Site impact can be caused by logging and/or site preparation treatments.
2. Growth: A subjective assessment of the growth, form, and vigour of regenerating crop trees was made. A ranking of poor to excellent was also given.
3. Stocking: The total stocking of all preferred and acceptable species was calculated, without spacing restrictions. A second value relating to the stocking of planted stems, if applicable, was calculated. An estimate of survival was made, based on actual stocking and spacing of surviving trees.
4. Vegetation: A brief description of the overall vegetation of the site was given, stating if competition has contributed to regeneration failure or poor height growth.

4.4 Data Analysis

All data collected, either from historical reconstruction or from field assessment, were entered into data base programs. This created a large body of data. Silvicultural and ecological (site) data were grouped into one data base; other data bases were as follows:

1. Height Growth and Stocking
2. Natural Regeneration
3. Competing Vegetation

Data bases were joined where necessary to allow sorting and identification of relationships.

Organization of data in this manner allowed two separate forms of analysis. First, the relationship between site/silvicultural factors and dependent factors (height growth, stocking, natural regeneration, competing vegetation) could be discerned. For example, it was possible to determine if natural regeneration was related to site impact. The results of this analysis is covered in detail in Chapter 5. Silvicultural and ecological factors used in this analysis are listed:

1. Ecological Factors

   Association (moisture regime on a scale of 1 to 8)
   Transect (drainage or geographic area)
   Range (either the Rockies or the Purcells)
   Elevation, aspect, slope
   Nutrient regime
   Soil classification, soil texture (top 15 cm)
   Soil drainage

2. Silvicultural Factors

   District
   Disturbance year, site preparation year, planting year
   Preparation delay, planting delay
   Species planted
   Logging method
   Stock type
   Site impact

For the purposes of this exercise, associations were assigned a number from 1 (xeric) to 8 (hygric). Mesic associations were assigned the number 5, regardless of ecosystem association as classified by Utzig *et al.* (1986).

Growth and stocking (both total and planted trees only) were entered into a separate data base. The height growth of planted trees was graphed by age since planting. Irregularities were evened out by hand. The result is a "normalized" or estimated growth curve (Figure 11) which shows mean height growth of planted Engelmann spruce in the ESSFa subzone, according to the sites sampled in this exercise. In Figure 11, the three curves separate height over age data into excellent, good, moderate and poor classes, defined below. Note that growth classes are defined in relation to the mean.

Excellent (4)	greater than mean height plus 1.2 times the standard deviation for that age;
Good (3)	greater than mean height plus 0.6 times the standard deviation for that age;
Moderate (2)	within 0.6 standard deviations of the mean height for that age;
Poor (1)	less than mean height minus 0.6 standard deviations for that age.

Re-assessed growth classes mostly agreed with subjective classes. Height growth was assigned a numeric ranking (1 to 4) for sorting purposes. Figure 11 may be useful for illustrating the expected performance of planted spruce in the ESSFa.

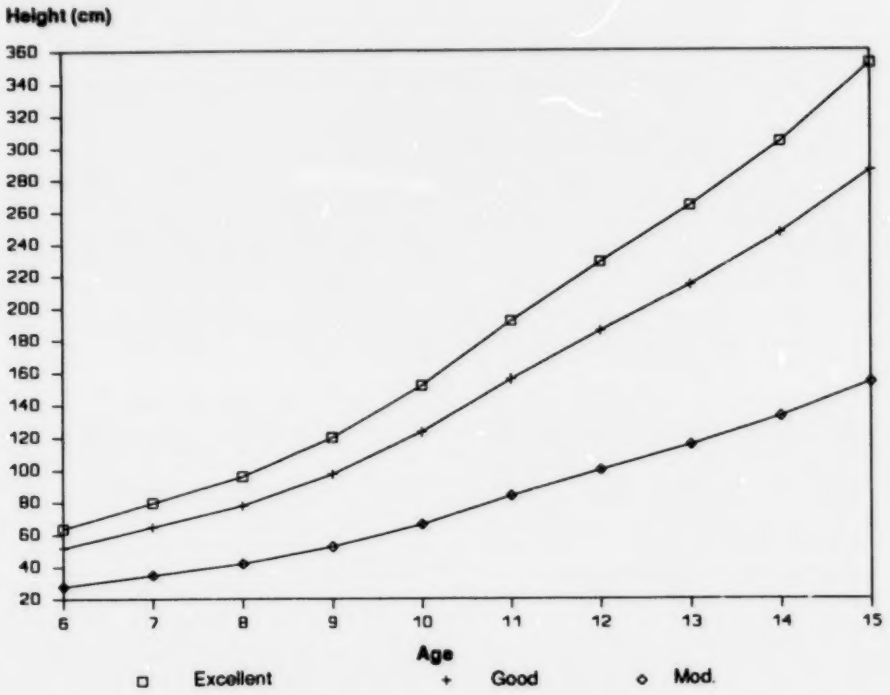


FIGURE 11. Estimated height growth: Engelmann spruce.

These manipulations allowed height growth, total stocking, and planted stocking to be used as dependent variables, with all other ecological and silvicultural factors as independent variables. Some factors, such as site impact, could be used both as dependent and independent factors.

Two other data bases were added to the analysis. Their contents are as follows:

1. Natural Regeneration

   Species

   Number of trees of each species in each of five height classes:

Class 1	0 - 50 cm
Class 2	51 - 100 cm
Class 3	101 - 150 cm
Class 4	151 - 200 cm
Class 5	201+ cm

2. Competing Vegetation

   Species

   Average cover of each species

   Average height of each species

   Frequency of each species (% occurrence in the five plots)

   Total cover of competing species

Each of the factors in these two data bases could be used as dependent or independent factors in the analysis.

The second analytical approach was to identify the most successful and the most unsuccessful examples of regeneration. In order to do this some internally consistent criterion of success was necessary.

Success implies satisfactory height growth in addition to stocking. The criterion employed must be a composite of these two factors. Sites were regarded as successful if growth was "moderate" or better and total stocking was greater than 1000 stems of acceptable or preferred species per ha. Separate analyses of plantations were also carried out, using a successful stocking criterion of 900 stems per hectare.

This second analytical approach allowed an assessment of individual treatments and ecological factors. For example, the ratio of successful to unsuccessful plantations established in the Invermere Purcells could be determined.

5 RESULTS AND DISCUSSION

This section reports the results of field data collection and analysis. The objective was to elucidate trends and patterns rather than to generate statistically rigorous conclusions about regeneration. These findings represent 65 sample sites located throughout the ESSFa. Sites were not randomly chosen.

5.1 Site Factors

5.1.1 Elevation

Figure 12 shows the relationship between elevational classes and growth of crop trees. Data show the relationship for lodgepole pine and spruce combined, and for spruce alone.

Between 1500 and 1700 m elevation, growth appears to be below average for spruce alone, and nearly average for the two species combined. In both categories, the growth index reaches a peak between 1700 and 1800 m. However, growth diminishes above 1800 m. The growth index for all plantations is 2.00 above 1800 m (average of 10 records) and 2.31 below (average of 36 records).

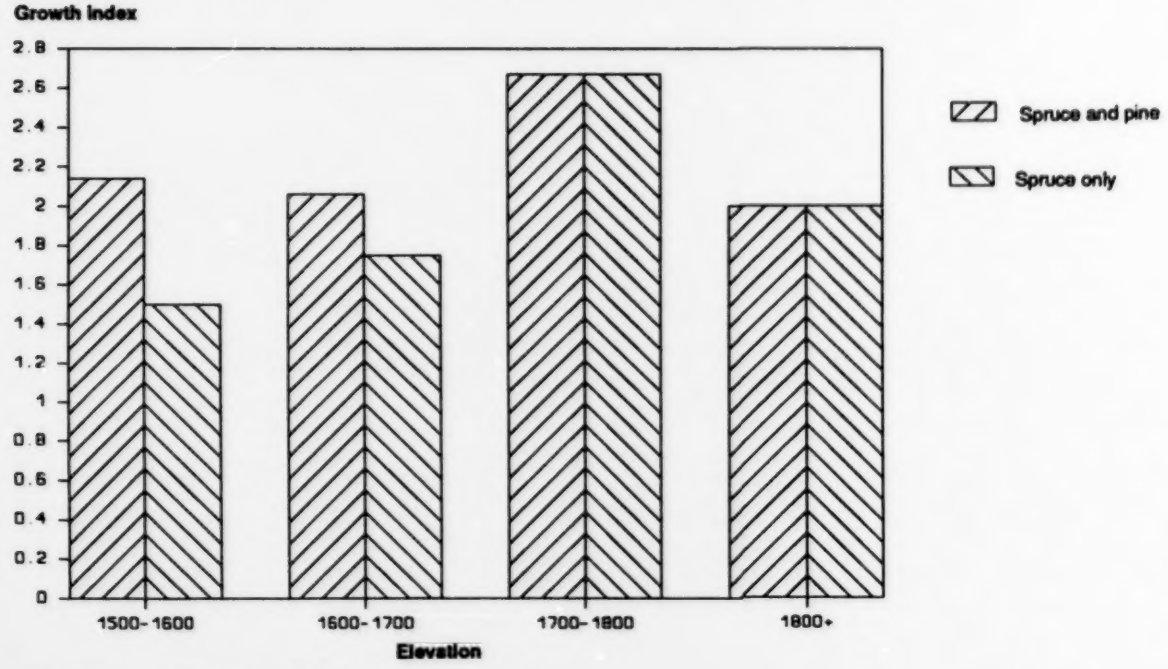


FIGURE 12. Growth of planted trees: by elevation.

Closer analysis of plantations located between 1600 and 1700 m show that 6 out of 17 exhibit poor growth (growth index less than or equal to 1), whereas only 1 out of 9 in the higher elevation class shows such poor growth. The reasons for this trend are unknown. Poor growth may be due to numerous factors other than those associated with elevation. However, one possibility is that frost damage may be greater at lower elevations in the mountains than at higher elevations (see Chapter 2). Incidence of frost during the summer growing period may be higher at low elevations in valley bottoms than at higher ones. The decline in growth index above 1800 m is probably due to the generally more severe environments.

Figure 13 shows the effect of elevation on average stocking of planted trees of pine and spruce combined, and of spruce alone. This stocking rate reflects both initial planting density and subsequent mortality. Initial stocking varied between about 1200 and 1400 stems per ha, but did not vary consistently with elevation.

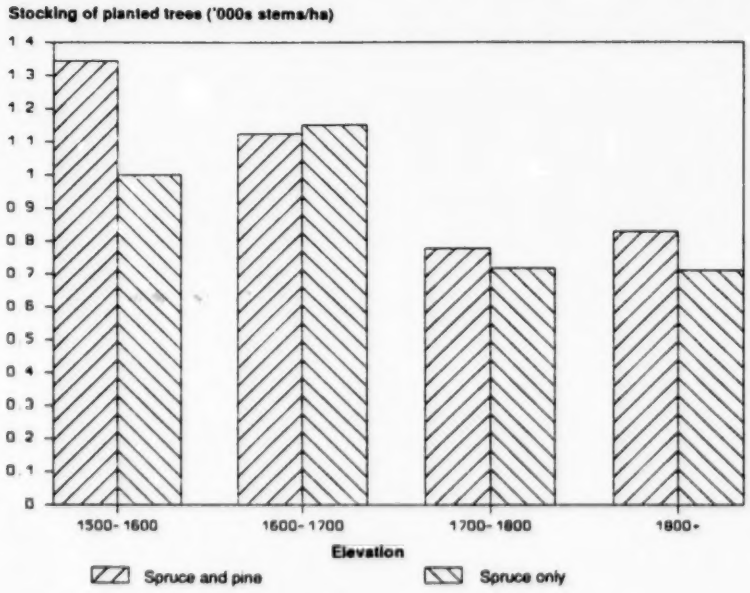


FIGURE 13. Stocking of planted trees: by elevation.

A general decline in planted stocking rates with increasing elevation is apparent. A substantial difference between stocking below 1700 m and above it can be seen. Overall, average planted stocking is 1024 below 1700 m and 765 above. The corresponding figures for spruce alone are 1174 and 733.

These data suggest that the environmental harshness associated with higher elevations is manifested more strongly in survival than in growth. Increasing elevation brings a shorter growing season and lower mean air temperatures over that season. Higher elevations are also associated with shallower soils (and steeper slopes). Thus, moisture stress may also be a contributing factor in high elevation mortality. One implication of these data may be to ensure high target stocking rates above 1700 m.

5.1.2 Moisture regime

Figure 14 shows the relationship between moisture regime and relative height growth. When both pine and spruce are combined, growth is fairly consistent between submesic and mesic associations, then drops off in wetter associations. Spruce grows best on mesic sites, and relatively poorly on drier associations.

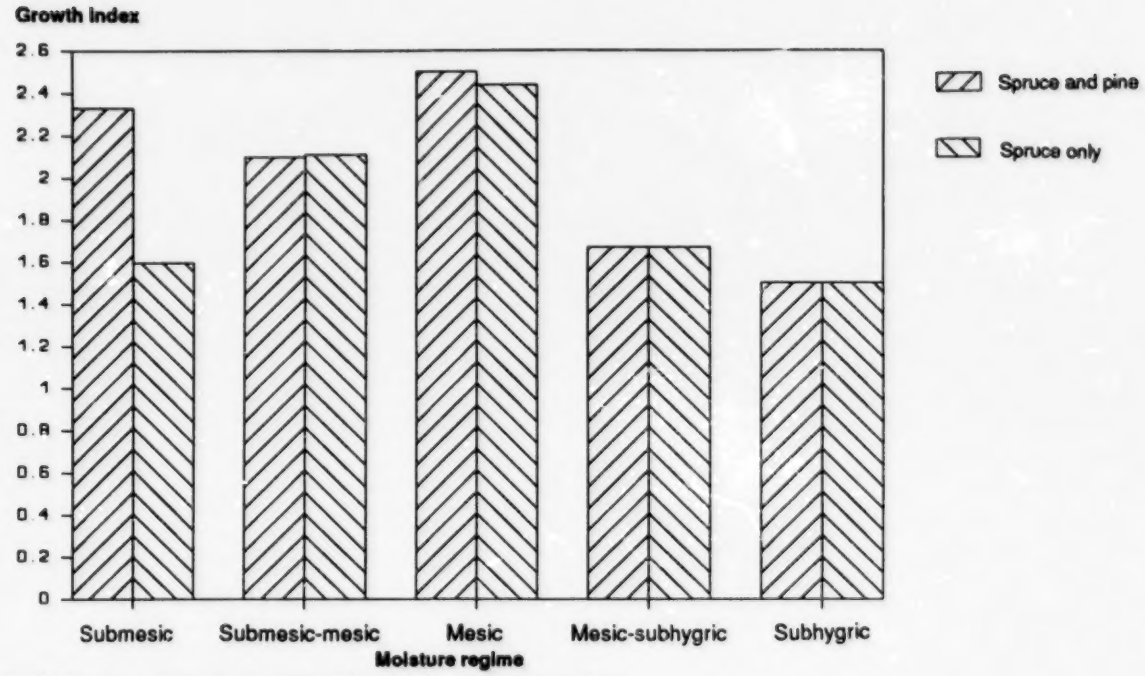


FIGURE 14. Growth of planted trees: by moisture regime.

The diminished growth in moister sites probably reflects a combination of competing vegetation, excess moisture, and cold soils.

These results conflict with the observation that the greatest potential for spruce growth lies within subhygric or mesic to subhygric sites, provided that high impacts have been sustained. In reality, this potential is infrequently realized on moist sites because of low site impact.

The highest growth indices are in mesic moisture regimes. Here growth potentials are realized to a large degree. Good height growth results from sufficient moisture to minimize moisture stress, but not so much that soil temperature, aeration and brush competition pose problems.

Figure 15 shows average stocking of planted trees grouped by moisture regime. No trend is apparent. However, stocking appears to be substantially lower on submesic-mesic and subhygric regimes. The reason for poor stocking on submesic-mesic sites is unknown. Further analysis of these sites suggests that higher than average mortality may be due to low site impacts in this group relative to other moisture regimes.

Poorer stocking in subhygric regimes can be explained by the same reasons affecting growth, mentioned above.

It should be kept in mind (especially at the pre-harvest assessment stage) that moist sites on lower slopes may experience a rise in watertables following logging. Beyond a certain threshold point on the moisture scale these sites will become extremely difficult to restock to existing guidelines. Where this happens, local minimum stocking standards should be changed. Alternatives may be to plant on existing favourable microsites, or to create microsites by mounding.

5.1.3 Moisture regime and site impact

Figure 16 combines moisture regime with site impact as groupings for examining crop tree growth. Note that in every moisture regime – except for submesic – growth is superior following high impacts than it is following low impacts. The growth differences appear to increase with increasing moisture.

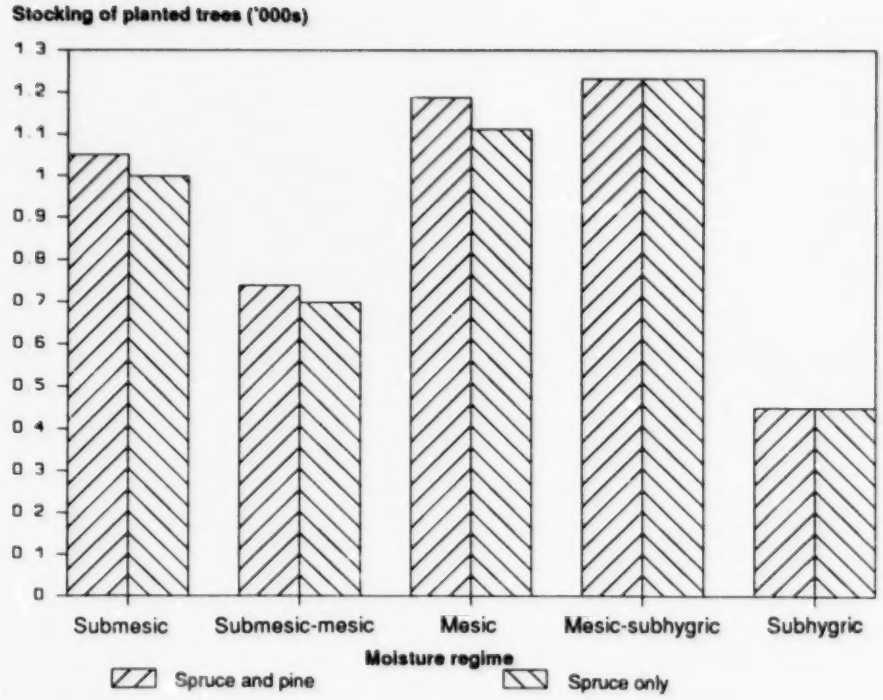


FIGURE 15. Stocking of planted trees: by moisture regime.

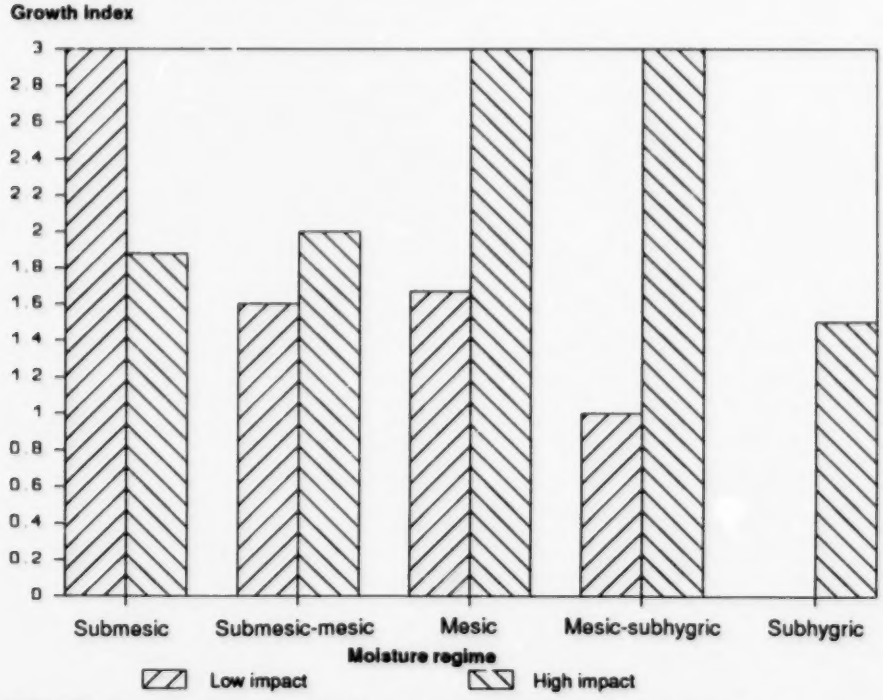


FIGURE 16. Growth of planted trees: by moisture regime and impact.

This diagram seems to be consistent with expectations and observations. In submesic regimes, high impacts can adversely affect crop tree growth by removing most or all of the nutrient capital, promoting physical and chemical soil degradation. It may also lead to widespread mineral soil exposure, thus encouraging frost-heave.

In mesic and mesic to subhygric regimes, where growth potential is highest, the difference between low and high impacts is great. Achieving a high impact treatment on sites in these moisture regimes is critical to plantation success.

The positive growth response to high impacts in both diagrams is consistent with the known ecological benefits of broadcast burning, namely: control of competing vegetation; amelioration of soil temperature and moisture regimes; and increased availability of nutrients (the Assart effect).

Figure 16 suggests that the highest growth potential exists on mesic or mesic-subhygric sites which have experienced a high impact.

Figure 17 displays the effect of moisture regime and impact on stocking. A clear trend is absent in this relationship, suggesting high variability and small sample numbers in some combinations, such as high impact, mesic-subhygric sites and low impact submesic sites. It is notable that for mesic sites, high impacts led to lower average stocking than did low impacts. The reasons for this are unclear.

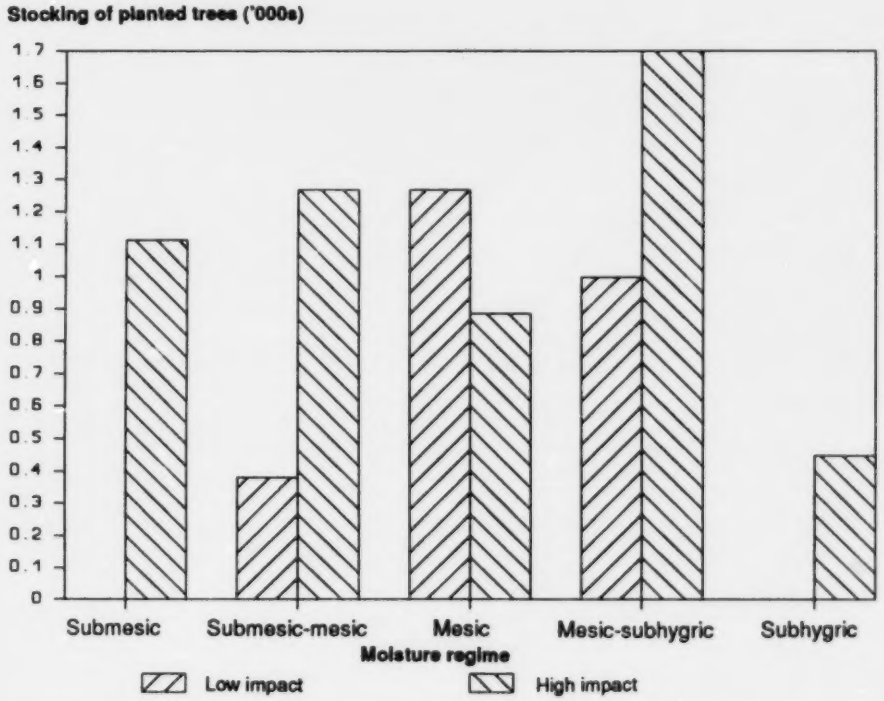


FIGURE 17. Stocking of planted trees: by moisture regime and impact.

5.1.4 Aspect and slope

In mountainous environments, it is likely that aspect and slope will have some influence on regeneration performance. Analysis of data obtained in this report suggest that aspect by itself affects relative height growth, but not planted stocking. This effect is aggravated on steep slopes. Note that average site impact is lower on north aspects and particularly low on steep north aspects. Average planted stocking on steep north aspects is only about three-quarters that on steep south aspects. It is probable that the reasons for poor relative performance on steep north aspects include the relatively low site impact.

TABLE 3. Effect of aspect and slope on regeneration performance

Slope/aspect class	Relative growth	Planted stocking	Modal moisture regime	Modal impact
All north (315 to 90)	2.08	1012	M	medium
All south (90 to 315)	2.47	974	SM-M	high
Steep north (> 20%)	1.78	689	M	low
Steep south (> 20%)	2.38	900	SM	high
Very gentle (<= 10%)	2.41	865	M	high
Gentle (>10 < 30%)	2.18	1018	M	medium
Moderate (>30 <50%)	2.43	693	SM-M	medium
Steep (> 50 %)	1.92	333	SM-M	low

Slope gradient by itself appears to have a relatively limited effect on regeneration performance, except above 50%. On such steep slopes, both relative height growth and planted stocking are substantially lower than on lower slope gradients. There are two possible reasons for this. First, broadcast burning is seldom intentionally carried out on these sites, because of control difficulties. Thus, site impacts are frequently low. Secondly, the soils associated with steep slopes are usually shallow and rocky, resulting in planting difficulty, unstable rooting media, and prolonged moisture stress during the growing season.

5.1.5 Competing vegetation

In the ESSFa, four main vegetative complexes were identified. These are as follows:

1. Fireweed complex
2. False azalea complex
3. Grass complex
4. Sitka alder complex

The fireweed complex consists of both herbaceous and shrubby species dominated by fireweed *(Epilobium angustifolium)*. Other prominent species include raspberry *(Rubus idaeus)*, thimbleberry *(R. parviflorus)*, swamp gooseberry (*Ribes lacustre*), Utah honeysuckle, *(Lonicera utahensis)*, black twinberry *(L. involucrata,)* and elderberry *(Sambucus racemosa)*.

Fireweed itself was the most commonly encountered species; it was present on 53 out of 65 sites sampled. On seven sites it was considered a serious competitor to conifer seedlings. On these sites average cover was greater than 20%, but in places it exceeded 70%. Average height of the complex was usually between 80 and 100 cm, but in one case it was about 130 cm.

The false azalea (*Menziesia ferruginea*) complex consisted of shrubs that were present in the stand before logging. Dominated by false azalea, other species forming this complex were black twinberry, swamp gooseberry, Utah honeysuckle, and white rhododendron (*Rhododendron albicaulis*). The false azalea complex was encountered on 7 of 65 sites. Average cover of false azalea ranged from about 15 to 90% and average height varied between about 50 and 150 cm.

The species composition of the grass complex varied with moisture regime. Pinegrass (*Calamagrostis rubescens*) was dominant in many mesic and drier sites, while sedges (*Carex* spp.) and bluejoint reed grass (*C. canadensis*) dominated wetter sites. Species of the genera *Poa*, *Elymus*, *Agrostis*, and *Bromus* were also common throughout.

The grass complex was recorded on 18 out of 65 sites. The average height of the blades was usually less than 50 cm.

The alder complex was dominated by Sitka or slide alder (*Alnus viridus* ssp. *sinuata*). This complex usually contained few if any other species. The alder complex frequently exhibited an irregular spatial distribution in sampled cutblocks. Most alder had established from seed onto mineral soils exposed through logging or site preparation. Alder was observed to be most prominent on skidroads located on north aspects. The alder complex was observed on 4 of 65 sites. Average cover was less than 30% in all cases, and frequency of occurrence was substantially lower than for other vegetation complexes. Average height of the alder complex ranged from about 150 to 300 cm.

Figure 18 shows the average percent cover of the four vegetation complexes. Clearly, the grass complex is the most important one, at least on the basis of average percent cover. It averages the highest cover in all circum-mesic moisture regimes.

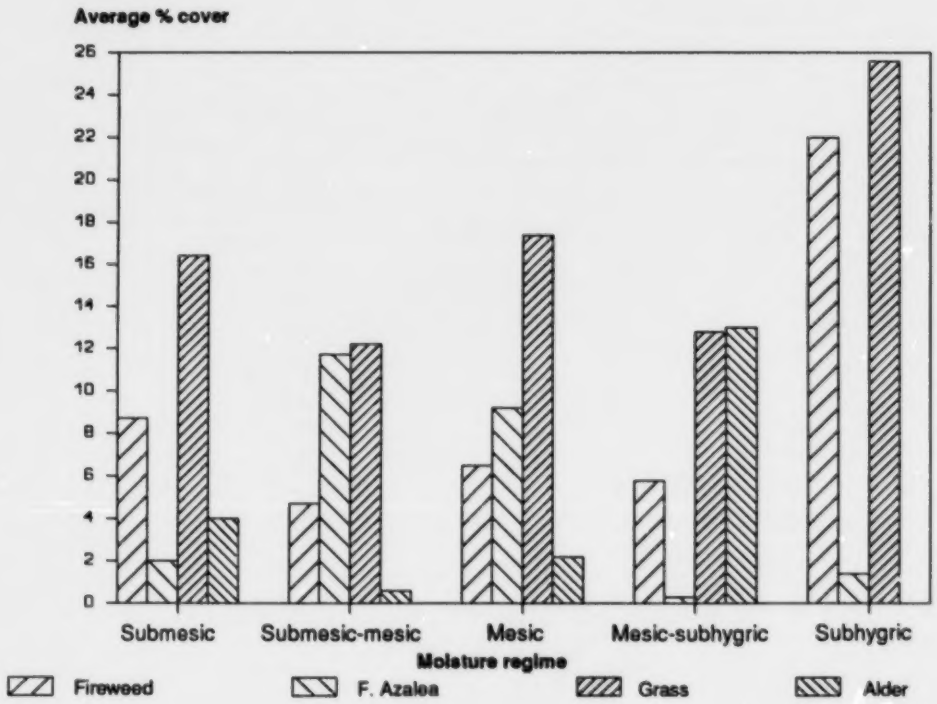


FIGURE 18. Cover of competing species: by moisture regime.

Grass cover can be very high on submesic and submesic-to-mesic sites where pinegrass invades lower elevations of the ESSFa. This was the case in the Lussier and White River drainages in the Rocky Mountains of the Invermere Forest District.

Fireweed generally exhibited average cover values less than 20%, except in subhygric regimes. It was observed to be a problem in a small number of openings.

False azalea (*Menziesia ferruginea*) reached highest covers on submesic-to-mesic sites and was virtually absent from sites moister than mesic in the openings sampled.

Figures 19-22 show the cover of each complex by moisture regime and site impact. When this latter variable is added, some predictions can be made as to where vegetation problems can be expected. Figure 19 shows that high fireweed cover may occur on mesic and wetter ecosystems which sustain a high site impact. In both cases, average cover is over 20%. When average cover exceeds this value, some part or parts of the opening may be experiencing covers of greater than 70%.

Because fireweed is likely to occur on these sites following high impact burns, and because high impacts are needed for satisfactory growth of spruce, the silviculturist must plan for fireweed competition. Prompt planting, possibly with large caliper stock, should be encouraged.

Figure 20 shows that false azalea is very sensitive to site impact. Significant cover values of this species are present only if a low impact treatment or no treatment was carried out. Although abundant false azalea can pose problems to establishing seedlings, it is a problem easily controlled if a satisfactory broadcast burn is prescribed and accomplished.

Grass cover is slightly impact-sensitive, to the extent that very low or very high impacts tend to diminish the extent of the complex. This is not true on wetter moisture regimes dominated by sedges. These species are apparently insensitive to the original site impact level.

Alder is generally an unimportant competitor of seedlings in the ESSFa. However, on a small number of sites it can pose a significant threat. Figure 22 shows that, among the sites sampled in this project, wet sites subjected to a high impact exhibited a substantial amount of alder. The site requirements of this species are mineral soil exposure for germination, and sufficient soil moisture for establishment and growth. Thus, exposure of mineral soil on subhygric sites may lead to alder invasion if a seed source is nearby (especially avalanche paths).

The previous diagrams have shown that substantial cover values of certain competing species can and do occur. However, what is their effect on the growth of crop trees?

Figure 23 compares average relative height growth for sites containing more than 20% cover with sites containing less than 20% cover. Growth seems to suffer only from high cover values of fireweed and false azalea. Stocking (Figure 24) is also lower on sites with high covers of these two species.

High covers (>20%) of grass and alder do not appear to be detrimental to crop tree growth. If anything, growth was slightly higher where grass cover was high. Growth was not adversely affected above any grass threshold cover, even above 70%. The very high cover values recorded on medium impact sites with a mesic to drier moisture regime have, theoretically, implications for seedling establishment and competition for soil moisture (Sloan and Ryker 1986). However, results from this study have not confirmed this effect, either for relative height growth or for planted stocking. It appears that pine, the most commonly planted species in grassy sites, competes well with abundant grass covers.

The effect of high grass cover was also not apparent on stocking. In fact, planted stocking was higher on sites with high grass cover than on sites with low cover (Figure 24), although the difference is not large.

Only one plantation with alder cover greater than 20% was sampled. However, this showed height growth and stocking rates much above average. It is expected that a threshold of alder cover exists above which growth and survival diminish, but that threshold appears to be above 20%.

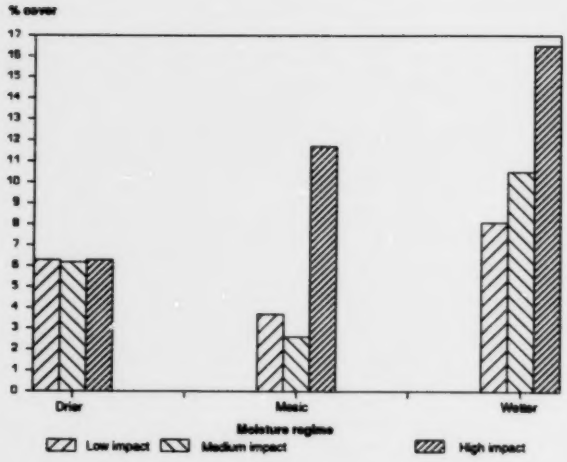


FIGURE 19. Fireweed cover: by moisture regime and impact.

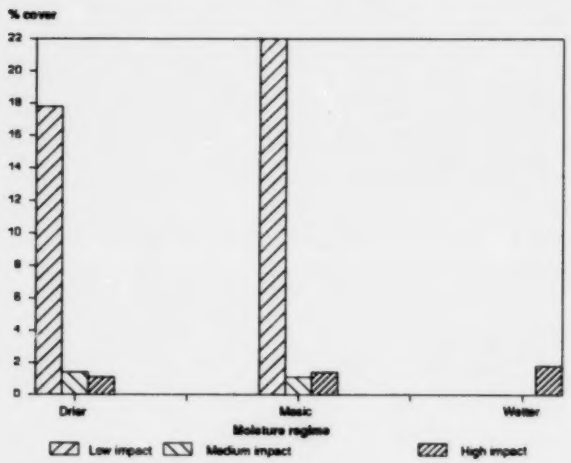


FIGURE 20. False azalea cover: by moisture regime and impact.

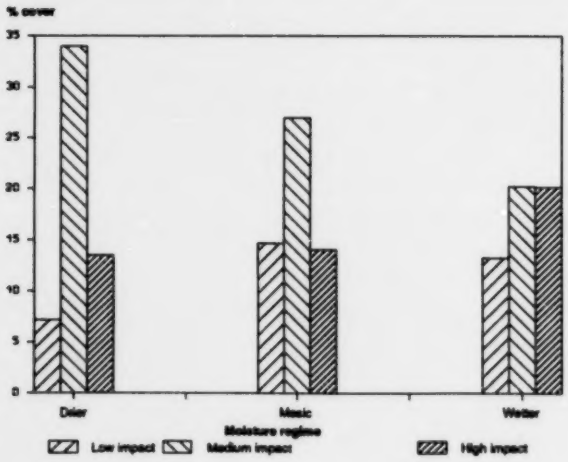


FIGURE 21. Grass cover: by moisture regime and impact.

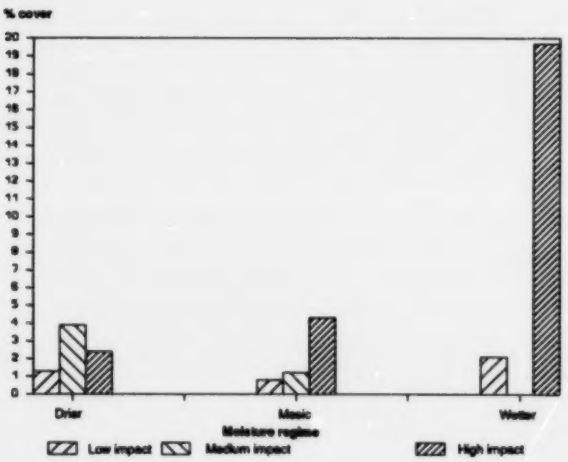


FIGURE 22. Alder cover: by moisture regime and impact.

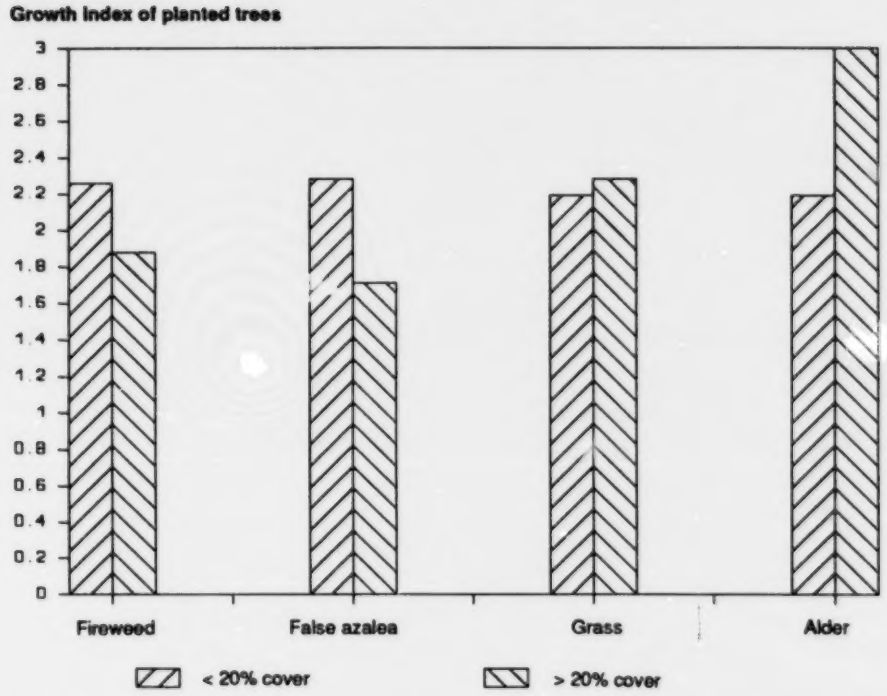


FIGURE 23. Effects of brush competition: average growth of planted trees.

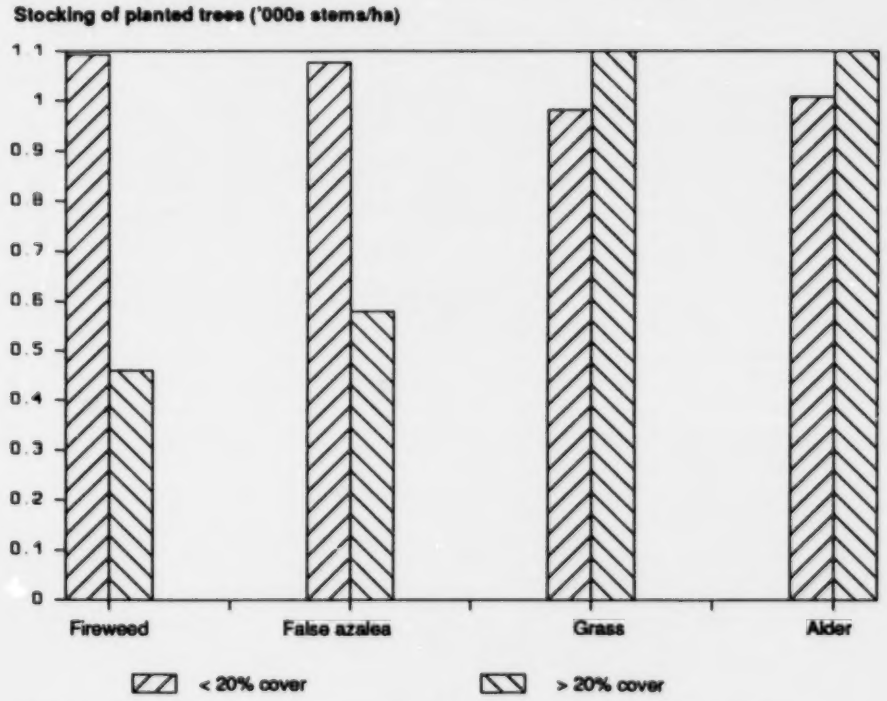


FIGURE 24. Effects of brush competition: average stocking of planted trees.

5.2 Natural Regeneration

Engelmann spruce and subalpine fir are the most important naturally regenerated species in the ESSFa. Lodgepole pine is relatively unimportant, although a few sites were fully stocked as a result of natural establishment of this species.

Engelmann spruce and subalpine fir regeneration is relatively unimportant below 1600 m (Figure 25) in the areas sampled. Above this height, subalpine fir accounts for a larger average stocking rate, including both advance and post-logging naturals. The average total stocking appears to decline somewhat above 1800 m.

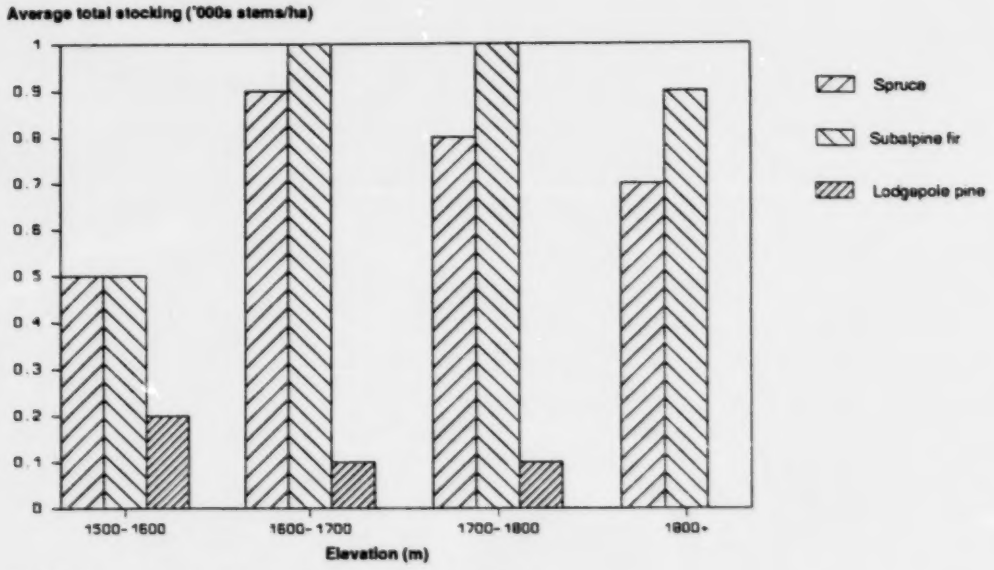


FIGURE 25. Natural regeneration: by elevation.

By moisture regime (Figure 26), subalpine fir is prominent on submesic-mesic sites, but drops off as site moisture increases. Spruce is the most important naturally regenerating tree on mesic and wetter regimes, and reaches a peak in average total stocking (nearly 1200 stems/ha) on mesic-subhygric sites. Here, natural regeneration of spruce can significantly augment planted trees. Note, however, that the diagram refers to total stocking; the actual number of well-spaced, acceptable trees may be substantially lower.

Figure 27 shows the distribution of natural regeneration on high and low impact sites. Stocking of subalpine fir is dramatically higher on low impacts, whereas spruce stocking is somewhat higher at high impacts. This is consistent with observations in the field and with published studies (Knapp and Smith 1981). Regardless of proximity to seed sources, low impact treatments favour subalpine fir at the expense of Engelmann spruce.

Figure 28 shows the height class distribution of naturally regenerated trees in all sampled openings which were created in 1970. The absolute numbers are unimportant, but the relative distribution amongst height classes is revealing. In both Engelmann spruce and subalpine fir, the majority of seedlings are still less than 50 cm tall, even after 17 years. If planted promptly, surviving spruce would be 200-250 cm tall. This diagram illustrates three effects:

1. natural regeneration of spruce and subalpine fir continues for a long period after an opening is created;
2. growth rate and survival of spruce and subalpine fir germinants are low on exposed openings; and
3. the time and volume lost by not planting immediately can be considerable.

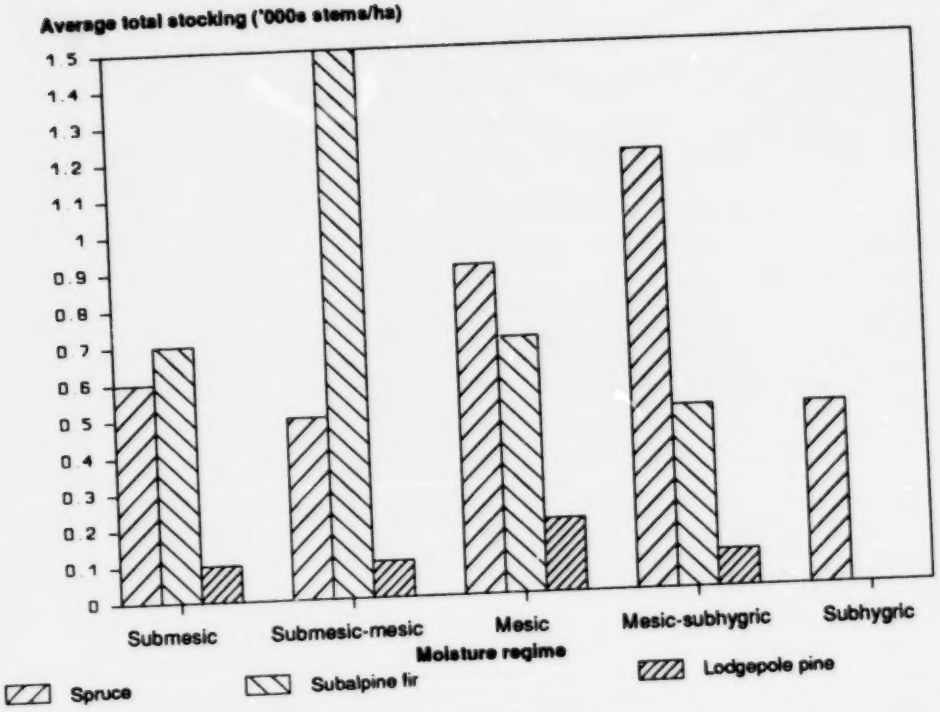


FIGURE 26. Natural regeneration: by moisture regime.

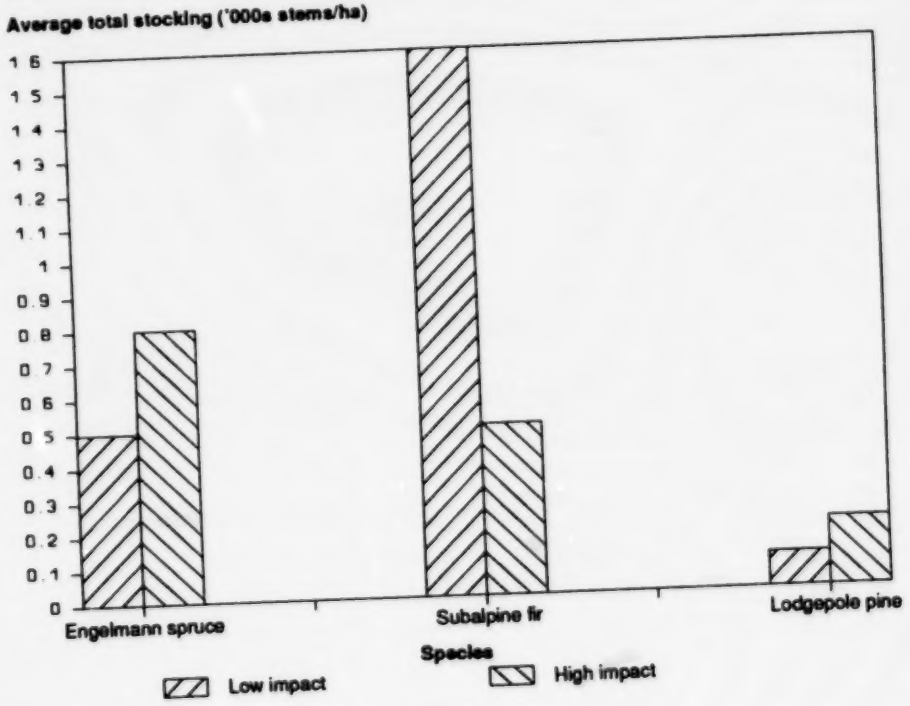


FIGURE 27. Natural regeneration: by impact.

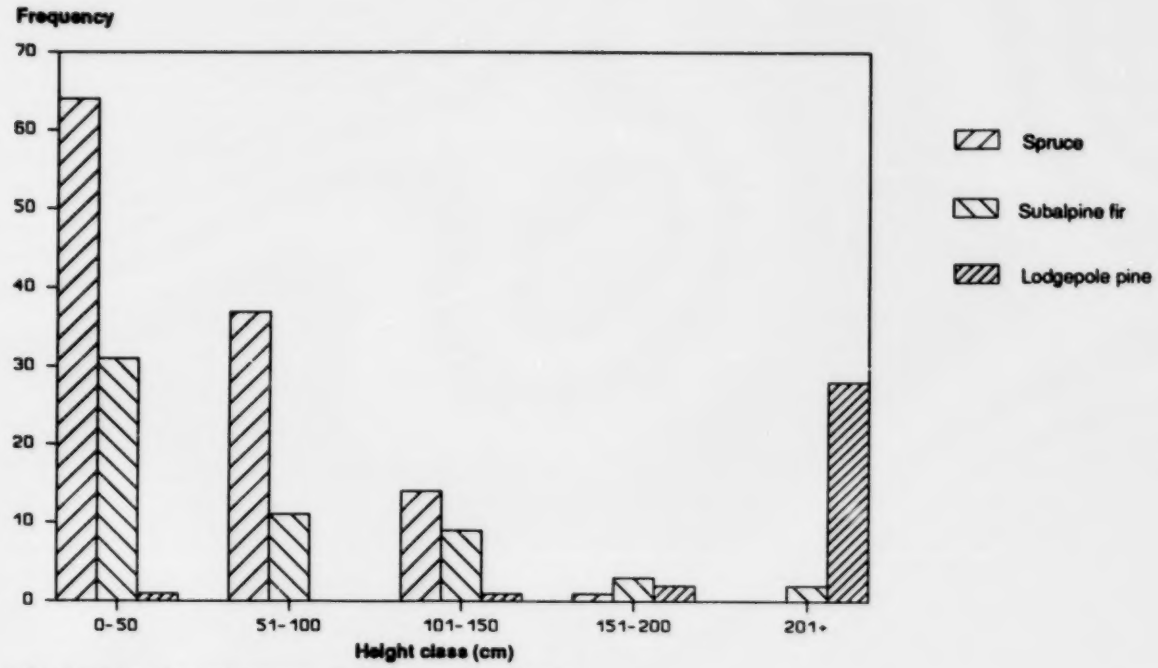


FIGURE 28. Natural regeneration: height distribution.

Note that lodgepole pine shows a different response. Most individuals are confined to the 200 cm plus height class. This reflects a small number of 1970 openings which contained pine regenerated from cones following disturbance. On other sites, lodgepole pine is a rather inconspicuous component of the natural regeneration.

Figures 29-32 show the effect of competing vegetation on total stocking of natural regeneration. Figure 29 indicates that high fireweed cover is associated with reduced subalpine fir but increased spruce regeneration. The probable reason for this is not the actual interaction between the regenerating trees and the competing vegetation, but the site requirements common to both seedlings and brush. Spruce regeneration is more prolific on moister sites (Figure 26) where fireweed is also abundant (Figure 19).

Figure 30 indicates that false azalea cover and subalpine fir are associated. This reflects the tendency for subalpine fir to establish on low impact sites which are associated with high covers of false azalea. Natural regeneration of spruce is greater on sites with low azalea cover, although spruce will establish on shaded low impact sites more effectively than on exposed low impact sites. It is interesting to note that spruce regeneration is greater under fireweed than under false azalea, at comparable average covers. In some sites, a dense fireweed cover may act as a nurse crop for spruce germinants.

Grass cover (Figure 31) inhibits establishment of subalpine fir, although part of the relationship in this diagram is due to the natural paucity of subalpine fir regeneration on the type of sites which may be subject to high grass cover. Grass litter may loft seeds, thereby dooming them to desiccation.

Alder appears to have relatively little effect on natural regeneration (Figure 32), with the exception of lodgepole pine. Again, this reflects the common site requirement of high impact or exposed mineral soil. Sites with an alder cover of greater than 20% are wetter, however, than most lodgepole pine sites.

5.3 Silvicultural Factors

5.3.1 Silvicultural system

The majority of openings in the ESSFa subzone have been clearcut. Of openings containing NSR, about 20% were harvested using a partial cut system (Butt 1987). Partial cutting included "selective," "diameter limit," and "seedtree" systems according to opening files, but the definitions associated with these terms have not always been consistent. Seedtree logging is associated with Douglas-fir and larch stands at lower elevations in the subzone.

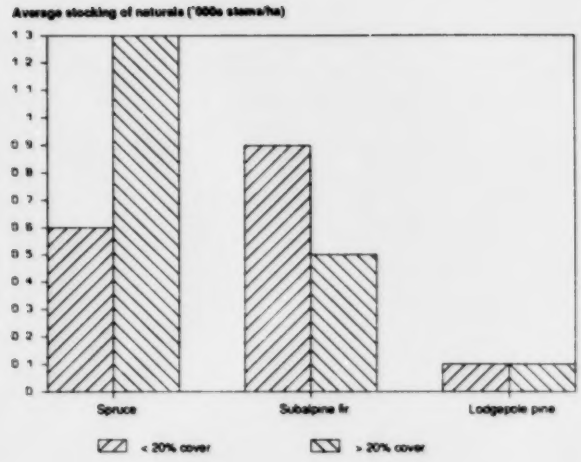


FIGURE 29. Effects of fireweed cover: on natural regeneration.

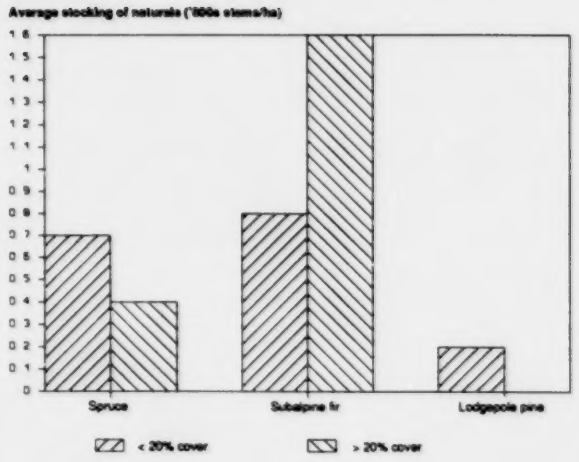


FIGURE 30. Effects of false azalea: on natural regeneration.

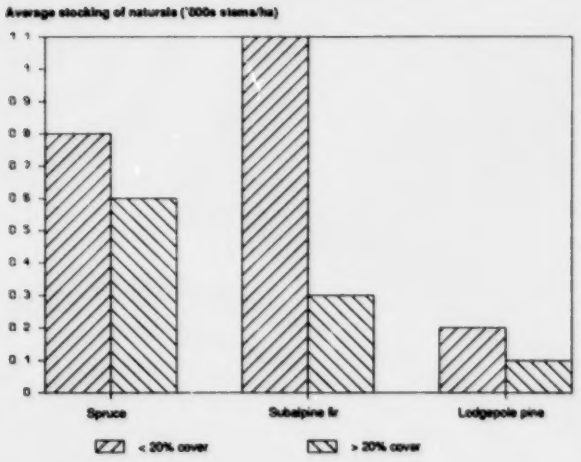


FIGURE 31. Effects of grass cover: on natural regeneration.

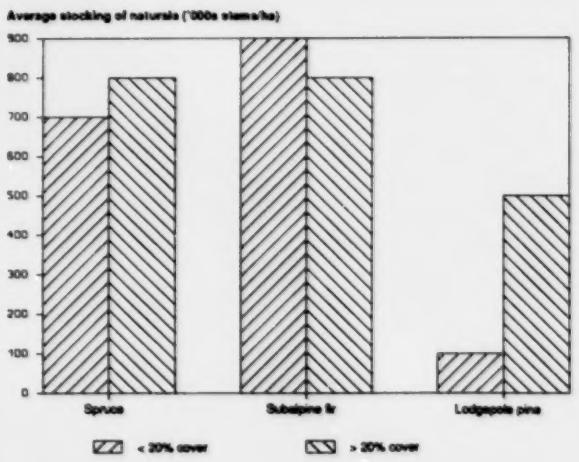
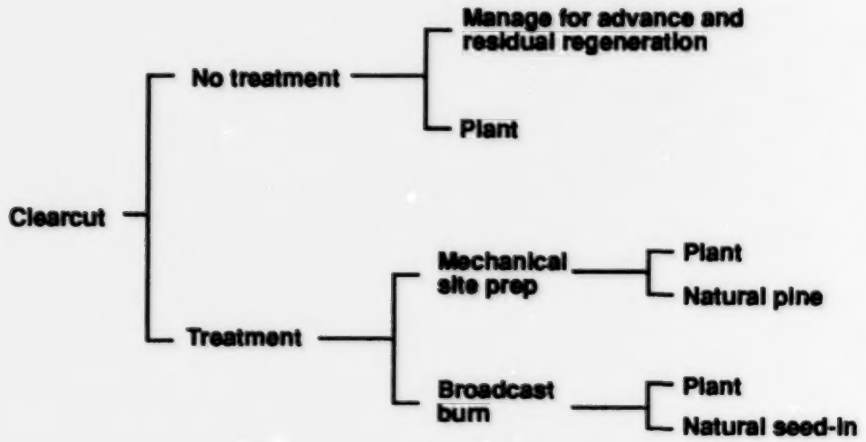


FIGURE 32. Effects of alder cover: on natural regeneration.

Of the 65 sites sampled, all but three were clearcut, reflecting the dominant logging method practiced in recent years. The distinction between clearcut and selective logging is not always clear. The term "clearcut" has been applied to sites in which numerous large residuals have been left.

Notwithstanding difficulties with the definition of clearcutting, the historical options for silvicultural management are outlined below.



Clearcut openings were either managed for natural regeneration or artificially regenerated. In the past, some sites were treated with the intention of planting, but for some reason (such as lack of stock) planting never occurred. For example, six sites which were broadcast burned and not planted were sampled. Conversely, a number of sampled sites were planted without prior treatment, mostly with limited success.

Clearcutting with retention of advance and residual regeneration is an acceptable alternative on certain sites. Overall 27 of the 46 plantations were successful, for a success rate of 59%.[1] This compares with a success rate of 63% (12 of 19 openings sampled) for openings clearcut but managed for advance regeneration. The criterion employed uses total stocking. A well-spaced stocking criterion would reduce the success rate of many of these stands. More than half were NSR using current Nelson Region stocking standards.

In addition to irregular stocking (and thus poor site occupancy), openings managed for residual and advance regeneration contained abundant trees of marginal quality and a very high ratio of subalpine fir to Engelmann spruce.

It should be recalled (Chapter 3) that nearly 20 000 ha or about two-thirds of the total NSR area, have been untreated. This was corroborated in an earlier study (Butt 1987) showing that 59% of all openings containing NSR land were unplanted. Much of this area has been managed for residual and advance regeneration. Historically, there is more NSR untreated compared to treated land (Figure 10).

Average relative height growth was slightly greater for planted sites (2.24) than for unplanted sites (2.16). However, no naturally regenerated tree exhibited excellent height growth. Residual and advanced regeneration were not included in height growth analysis.

Total stocking (including all regeneration) was greater on unplanted than on planted sites (1728 vs 1542 stems per hectare). The difference would no doubt have been greater if all unplanted sites were also untreated.

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[1] The "success" criterion for all sites (planted and unplanted) is: growth moderate or better and total stocking greater than 1200.

5.3.2 Site treatment

Broadcast burning was used on 35 out of 65 sites sampled (54%), although historically it was used on only 4206 ha or about 12% of the total area logged (see also Figure 9). However, broadcast burning is now the favoured treatment on currently logged sites, having recovered from an extended period of disfavour between 1975 and 1985.

A number of sample sites were in areas consumed by wildfires (namely, the Bloom Creek and Jumbo Creek areas). These were treated as "burned" sites.

Mechanical site preparation was applied in only two sites sampled, or about 3% of the total number of sites. Historically (Figure 9), about 15% of the logged area was mechanically prepared, although slightly more than half of this was chain dragged for natural pine regeneration. Because of their small number, sites which were mechanically prepared were lumped with others under the treatment category "not burned."

Table 4 summarizes growth and planted stocking for spruce plantations. Note that there is little difference in average growth or stocking when all "burned" sites are compared with all "not burned" sites. When treatment types are separated into impact classes some differences appear. Medium impact, unburned sites stand out as having the best height growth and stocking for spruce. This result is due to the small number of samples in this class, and the fact that one of them exhibited the best spruce growth (but not survival) in the survey. Otherwise, little difference is seen between burned and unburned treatment groups.

TABLE 4. Growth and stocking of spruce plantations, by treatment type and relative impact

	Burned		Not burned	
Treatment/Impact	Growth	Stocking	Growth	Stocking
Low impact	1.71	714	1.25	950
Medium impact	2.00	1100	2.67	1333
High impact	2.30	990	2.25	962
All impacts	2.05	910	2.07	1007

In both treatment classes, low impacts resulted in poor growth and stocking. On average, high impact burns promoted better growth than low or medium impact burns, although average stocking was superior on medium impact burns. These results are consistent with the finding that plantation success (using both height and stocking criteria) is highest on medium impact sites (Figure 36).

Excessive site impacts resulting in site degradation were observed on several of the mechanically prepared sites. Growth and stocking on these sites were poor. This observation stresses the need for greater care when prescribing and directing mechanical treatments.

5.3.3 Preparation and planting delays

The results of this exercise do not show a clear relationship between site preparation delay (the time between logging and site preparation) and regeneration performance. This is at least partly due to the small numbers of samples on sites with long (> 2 years) preparation delays. The results are also affected by the considerable logging impact on a number of sites, particularly on drier moisture regimes.

Table 5 shows the results of the effects of increasing site preparation delays on relative growth index, planted stocking and site impact for all plantations. Growth and stocking do not decrease with increasing preparation delay. Impact, strangely, is highest following preparation delays of 3 and 4 years. Both of these sample sites were burned.

TABLE 5. Preparation delay effects on regeneration performance

Preparation delay (years)	Growth index	Planted stocking	Impact	Moisture regime	No. of samples
0	2.08	988	medium	SM-M	25
1	2.71	957	high	SM-M	7
2	2.30	1160	medium	M	10
3	2.50	1100	high	SM	2
4	2.00	950	high	M	2
> 4	—	—	—	—	0

Among sites which were broadcast burned, preparation delay had no discernable effects on relative growth indices. However, stocking of planted trees was lower on sites with a preparation delay greater than 2 years (867 trees per hectare, on average) than on sites with shorter delays (1058 trees per hectare).

Planting delays greater than 3 years adversely affected regeneration performance. Overall, increasing planting delay from 0 to 3 years made no difference in relative growth or planted stocking, even on mesic and wetter moisture regimes. Delays greater than 3 years caused reductions in relative growth but not in planted stocking. The reduction in relative growth is especially notable on mesic and wetter moisture regimes (Table 6).

TABLE 6. Planting delay effects on regeneration performance

	Planting delay all sites		Planting delay mesic and wetter only	
	= < 3 Years	> 3 Years	= < 3 Years	> 3 Years
Growth	2.32	2.00	2.40	1.83
Planted stocking	1032	1000	1047	1117
Average impact	high	low	medium	low
Average moisture regime	SM-M	SM-M	M	M

5.3.4 Species selection

Figure 14 suggests that the relative growth of lodgepole pine is superior to spruce on submesic sites. On these sites, the average relative height growth of spruce and lodgepole pine were 1.60 and 2.83, respectively. Average planted stocking rates are 1000 and 1267 trees per hectare, respectively, however, this reflects higher initial planting densities for pine. Five spruce plantations on submesic sites were sampled. These represent examples of incorrect species selection; pine would have been a better choice.

Douglas-fir was planted on only two sites sampled: both at about 1600 m in the Lussier Creek area of the Invermere Forest District. Height growth was promising, although survival was spotty in one plantation. There, backlog fill-in planting was carried out, again with Douglas-fir, about 6 years after the initial planting. Growth and survival of the second planting were dismal. Although too few Douglas-fir sites were sampled for conclusions to be generated, it seems that this species is suited to drier and/or high impact sites at lower elevations in the ESSFa subzone. It has been recommended that Douglas-fir be planted below 1800 m (Utzig *et al.* 1986).

5.3.5 Planting stock and quality

Planting stock and quality information was not always available. Therefore, these factors were not used for sorting in this analysis. Of the 46 plantations sampled, planting stock is recorded for only 31. Twenty-five of these were bareroot. Only four plantations were recorded as having container stock. None of these were successful (on the basis of growth and stocking), but failure was not apparently related to stock type.

Most plantations sampled were spring planted with cold-stored stock. Planting was usually carried out between late May and late June. No association between planting date and regeneration performance was evident. Two lodgepole pine plantations were planted in October, presumably with hot-lifted stock. Both had poor survival (38 and 48%) and highly variable height growth. There was no record of hot-lifting spruce stock.

Opening file information suggests that stock and planting quality has contributed to unsatisfactory performance on a number of plantations. Common problems were mouldy stock, stock flushing, and roots too long or too short. Planting difficulty was cited as a problem on steep and rocky sites. J-rooting appeared to be a problem with large transplant stock and in rocky areas. Planting difficulty has probably contributed to poor relative height growth and planted stocking on steep (> 50%) slopes (see 5.1.4)

5.4 Plantation Success Rate

5.4.1 District and mountain range

Figure 33 and Table 7 show the total numbers and ratios of successful to unsuccessful[2] plantations by forest district and by mountain range. Among sampled plantations, Invermere forest district has enjoyed a higher success rate than has Cranbrook.

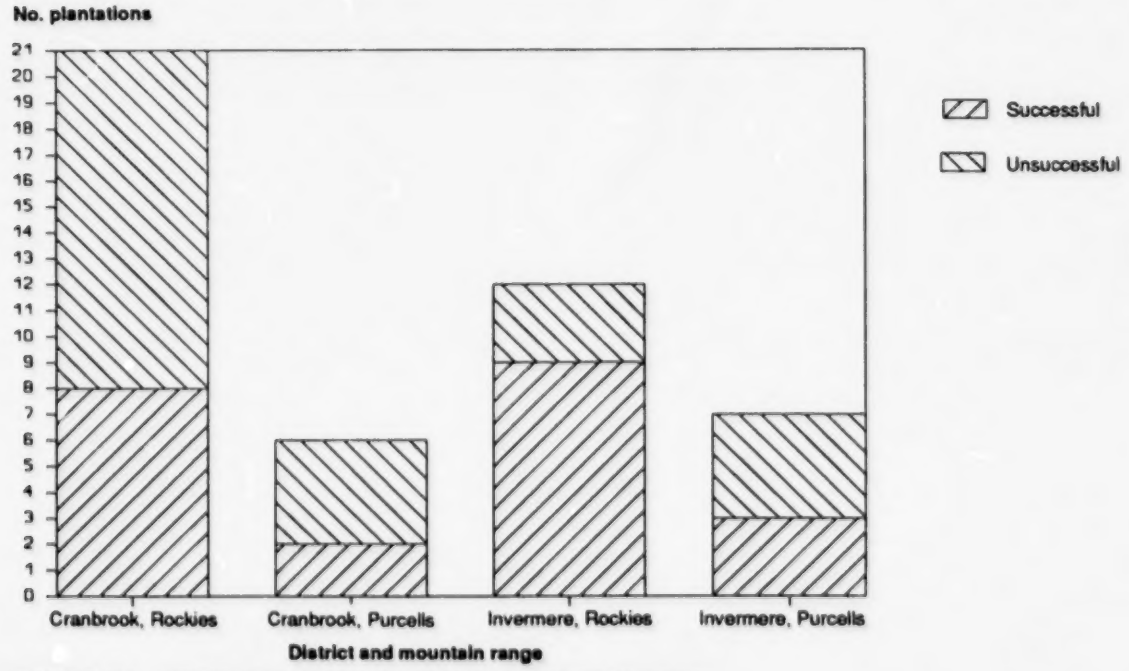

FIGURE 33. Plantation success: by district and mountain range.

[2] "Successful" is defined as an average growth index of fair or better and a stocking of planted trees over 900 stems per hectare.

From Table 7 it would appear that the Purcells are more difficult to regenerate artificially than the Rockies, even though ecological conditions are, superficially, the same. The average elevation, slope and moisture regime are identical in both ranges. Average total vegetative cover is greater in the Rockies (41.1%) than in the Purcells (23.2%), largely reflecting high pinegrass covers in the Invermere Rockies.

TABLE 7. Forest district and mountain range: plantation success rate.

Forest District	Plantation success rate (%)		
	Purcells	Rockies	Total
Invermere	43	75	63
Cranbrook	33	38	37
Total	38	52	48

The probable reason for the disparity lies with the manner of site treatment. Of a total of 13 plantations in the Purcells, only two were broadcast burned; the remainder were untreated. In several cases logging impact was high, and in two other cases planting followed a wildfire. In contrast, 30 out of 33 plantations in the Rockies were broadcast burned.

In the Invermere Purcells, three sites were broadcast burned, then left for natural regeneration, probably because of lack of planting stock. All three were NSR.

Plantation success diminishes above 1700 m elevation (Figure 34). Success is restricted at high elevations by reduced stocking levels. Relative height growth seems to diminish above 1800 m, but not below this level (Figure 12). Fourteen of 24 plantations below 1700 m were successful, for a success rate of 58%. This compares to only 4 of 16 successful plantations above 1700 m, for a success rate of 25%.

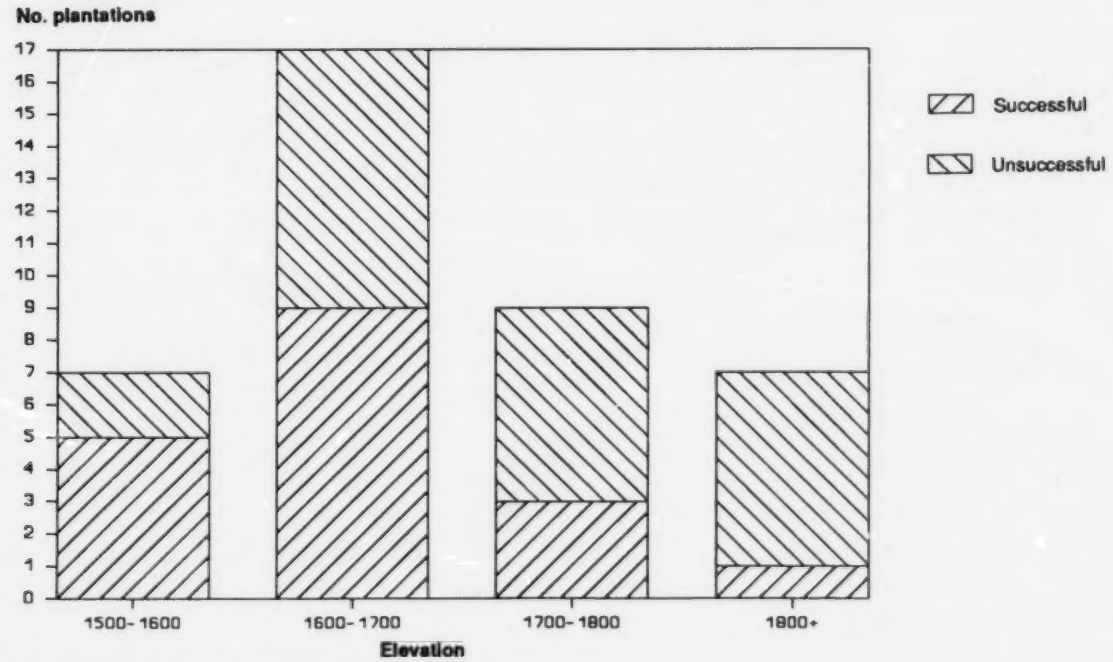

FIGURE 34. Plantation success: by elevation.

Figure 35 shows the number of successful and unsuccessful plantations by moisture regime. Mesic sites appear to have been most successful. The success rate on these sites is 56% (10 of 18 sites). This compares with success rates of 41% (9 of 22 sites) on drier sites and 20% (1 of 5) on wetter sites. The success rate on submesic to mesic sites is low (30% or 3 of 10) because average impacts were distinctly lower on these sites than on mesic or submesic sites.

Figure 36 suggests that medium and high impacts are conducive to relatively high success rates. Sites sustaining medium impact levels had a 67% success rate (8 of 12 sites). Sites with high impacts were successful in 50% of the cases (6 of 12 sites). These rates are favourable compared to those for very low impacts (15% or 3 of 20 sites) and to those for very high impacts (22% or 4 of 18 sites).

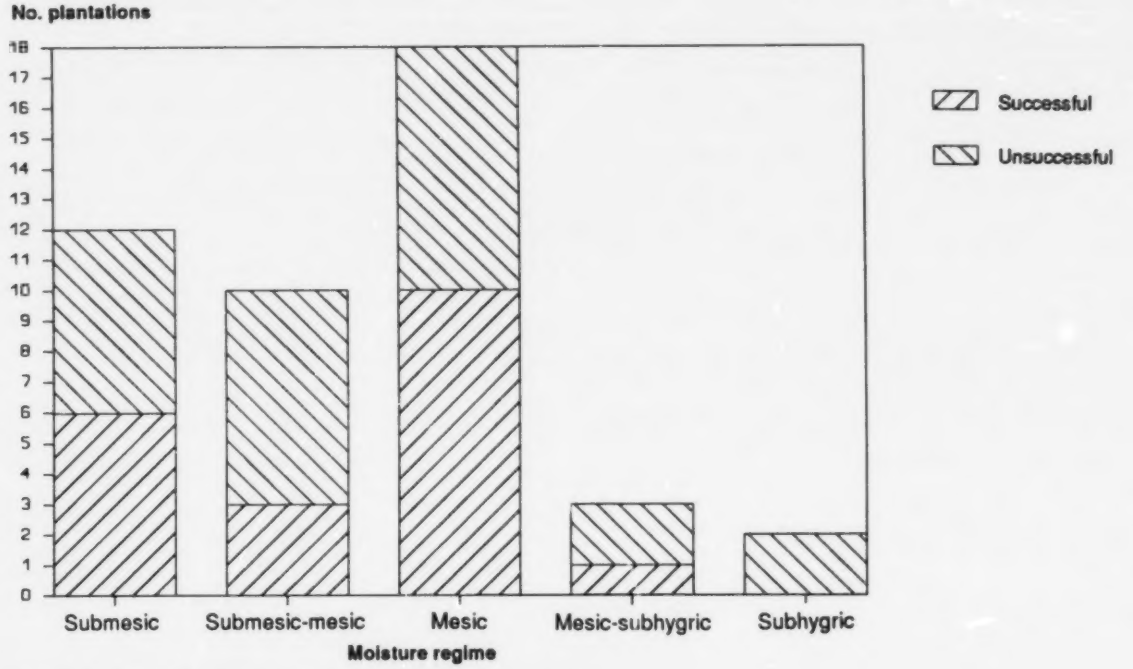

FIGURE 35. Plantation success: by moisture regime.

5.5 Description of Best Plantations

Table 8 lists all sampled plantations which exhibited good or excellent relative height growth, and a planted stocking rate in excess of 1000 trees per hectare.

All of these plantations have been burned, either from prescribed broadcast burning or from wildfire. All spruce plantations in the list were established after a high impact on sites with a moisture regime close to mesic. Conversely, most pine plantations were established following medium impact prescribed burns, usually on drier sites.

In all cases, preparation and planting delays were less than or equal to 2 years. Tables 4 and 5 suggest that preparation delays do not affect average relative growth or stocking and that planting delays over 3 years result in diminished height growth, but not stocking. Taken together, these results suggest that minimal delays allow excellent plantation performance, but do not guarantee it. The implication is that to achieve best growth and survival, silvicultural delays should be minimized.

Note that of this list of 10 best plantations, only 2 were located in the Purcell Range, and both were planted following wildfire. All were planted between 1972 and 1978 at elevations ranging from 1500 to 1780 m. There was no slope or aspect which characterized the list of sites.

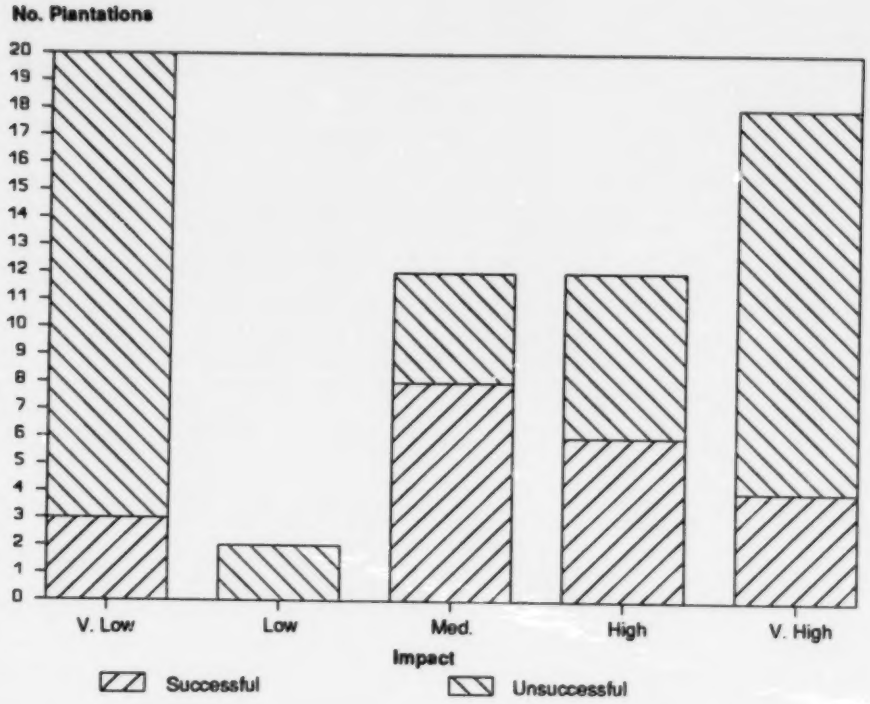

FIGURE 36. Plantation success: by impact.

TABLE 8. Summary of best plantations

Species Planted	Area	Elevation	District	Mountain range	Moisture regime	Site preparation	Impact level
Spruce	Harvey Creek	1630 m	Cranbrook	Rockies	SM-M	BB	High
Spruce	Harvey Creek	1515 m	Cranbrook	Rockies	M	BB	Very high
Spruce	Cabin Creek	1625 m	Cranbrook	Rockies	M-SHG	BB	High
Spruce	Bloom Creek	1740 m	Cranbrook	Purcells	M	WF	High
Spruce	Jumbo Creek	1500 m	Invermere	Purcells	SM-M	WF	High
Pine	Harvey Creek	1630 m	Cranbrook	Rockies	SM	BB	Medium
Pine	Lussier Creek	1780 m	Invermere	Rockies	SM	BB	Medium
Pine	Lussier Creek	1520 m	Invermere	Rockies	M	BB	Medium
Pine	Lussier Creek	1500 m	Invermere	Rockies	SM	BB	High
Douglas-fir	Lussier Creek	1610 m	Invermere	Rockies	SM-M	BB	Medium

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Historical Analysis

Between 1961 and 1985, nearly 60 000 ha of forest were denuded in the ESSFa, mostly in the Invermere and Cranbrook Forest Districts. Of that total area, more than half, or more than 30 000 ha are classed as NSR. The Ram fire in 1985 contributed about 16 000 ha or about one-half the total NSR area.

The percent NSR land is higher for recent (post-1975) than for older logging. This reflects the tendency for older blocks to regenerate naturally over time, and the fact that the figures combine current with backlog NSR.

Different treatments are associated with different amounts of NSR land. Overall, "no treatment" has the highest failure, whereas broadcast burning and windrowing have relatively low failure rates. Broadcast burning had fallen into disfavour between 1975 and 1985, but has re-emerged as a significant site treatment in recent years.

The implications of this analysis are that broadcast burning and windrowing are the treatments most likely to lead to success, and that even with no treatment, most openings will eventually restock.

6.2 Site Factors

A number of site factors appear to affect regeneration performance.

6.2.1 Elevation

Relatively poor average height growth between 1500 and 1700 m may be due to cold injury. Many plantations at those elevations were located on lower slopes or valley bottoms which may have been prone to frost. Cold injury and leader die-back due to frost were commonly observed in the field, particularly on moist sites.

Relative height growth diminishes above about 1800 m, while total planted stocking begins to diminish at a lower elevation, about 1700 m. These two trends result in lower overall plantation success above 1700 m.

This does not mean that regeneration is too difficult to achieve at higher elevations. In fact, one of the 10 best plantations sampled was located at 1780 m (Table 8). However, it must be realized that the probability that unacceptable regeneration will occur is higher above 1800 m than below it. Solutions to this problem may include setting higher target stocking levels, relaxing minimum stocking standards, or accepting longer regeneration and free growing delays.

6.2.2 Moisture regime

Lodgepole pine exhibits best relative height growth on submesic to mesic moisture regimes. Height growth indices drop on wetter sites. Engelmann spruce grows best on mesic sites, and less well on drier and wetter sites. The effects of moisture regime on stocking are unclear, but lower stocking rates should be anticipated on subhygric sites.

These results suggest that pine is preferable (from the point of view of height growth performance) to spruce on all sites drier than mesic. This is particularly true on high impact sites. In the past, spruce has been incorrectly prescribed on such sites.

Reduced stocking rates on subhygric sites should be reflected in minimum stocking standards lower than the 1000 well-spaced stems per ha advocated in Utzig *et al.* (1986).

6.2.3 Aspect and slope

Steep north aspects stand out as having poor historical relative height and stocking performance. These sites, on average, experience low impact treatments if they are treated at all. Average cover of false azalea, which is present in pre-logging stands, is frequently high on steep north aspects. On many otherwise successful openings, strata located on steep north aspects have failed.

Relative height growth and planted stocking are also lower on steep (> 50%) slopes than on gentler slopes. This is due to a combination of planting difficulty and adverse ecological conditions. Average site impact is low on steep sites, because of high site sensitivity to broadcast burning and limitations to mechanical treatment. Considerable site degradation associated with skidder logging on steep slopes was also observed.

6.3 Vegetative Competition

Four vegetation complexes have been identified in the ESSFa. These are:

1. fireweed (with variable amounts of thimbleberry and raspberry);
2. false azalea (occasionally with rhododendron);

3. grass (consisting of pinegrass-dominated communities on drier sites and Carex-dominated communities on wetter sites); and

4. slide alder.

The grass complex, on average, had the highest cover on all moisture regimes. Average cover was particularly high on subhygric sites, due to mixtures of *Carex* spp., *Calamagrostis canadensis*, and other grasses. Grass was unusually extensive in the Rockies in the Invermere Forest District, notably the Lussier and White River drainages, where pinegrass grew prolifically on mesic sites.

Grass competition appears not to have significantly affected either height growth or planted stocking in this study. More intensive study of pinegrass sites may prove otherwise.

The fireweed complex was commonly encountered. It was most serious, as competition for conifers, on highly impacted moist sites. Fireweed has been shown to have a deleterious affect on both relative height growth and planted stocking. Foresters should identify sites where fireweed will form high cover values and plan accordingly by minimizing planting delays and prescribing large caliper stock.

The false azalea complex was common on submesic to mesic and mesic sites which had sustained low impacts. Other species included black twinberry and utah honeysuckle. In general, the plants in this complex can easily be controlled by prescribed fire or mechanical site preparation. False azalea can reduce relative growth and contribute to the mortality of planted seedlings.

Slide, or Sitka, alder was not commonly encountered in this exercise. Average cover of this species was below 30% on all sampled sites. Alder was most abundant on wetter sites which had experienced high impacts, particularly if mineral soil was present as a substrate. Negative effects of alder competition on conifer growth were not observed in this study, but it is likely the species may interfere with growth and survival above certain threshold cover values. Isolated cases of seedling mortality due to suppression by alder were observed.

6.4 Natural Regeneration

Naturally established Engelmann spruce and subalpine fir can contribute significantly to the total stocking on a site, particularly above 1600 m. Lodgepole pine is relatively insignificant as a naturally established species overall, but is important on some sites. Subalpine fir is relatively insignificant on wetter sites, but is present in large numbers on submesic-mesic sites. Spruce is present in large numbers on wetter sites.

The distribution of naturally established subalpine fir is highly dependent on site impact. Sites receiving low impact are more likely to contain high densities of natural subalpine fir than Engelmann spruce. Sites sustaining high impacts appear to be more receptive to the natural establishment of spruce.

Post-logging recruitment of seedlings is a slow process. Naturally established seedlings were mostly less than 100 cm even after 17 years, whereas planted seedlings would be about 280 cm on good sites.

6.5 Silvicultural Factors

6.5.1 Site Impact

On mesic and mesic to subhygric moisture regimes, relative height growth is dramatically higher on high impact sites than on low impact sites. Growth potential on these sites is excellent, but can only be achieved by obtaining high site impacts. On submesic sites, high site impact can reduce relative height growth. The effect of site impact on stocking levels is not clear, although on mesic-subhygric sites, high impact sites had higher stocking levels than low impact sites.

6.5.2 Silvicultural system

Historically, most openings in the ESSFa subzone have been clearcut. About two-thirds of the total NSR area has had a history of clearcutting with no treatment. The percentage NSR land for this system is generally higher than for other systems. It is a major reason why the ESSFa contains such a disproportionate amount of NSR land.

In some cases, clearcutting and managing for advanced and residual regeneration is an acceptable practice. The criteria for predicting which sites are suitable to this management system have been developed elsewhere (e.g., Monchak 1982). Unless a site contains a sufficient stocking of acceptable, undamaged advanced and residual trees, this will be an inappropriate system. Drawbacks include uneven stocking, sub-optimal species composition, and high numbers of marginal quality trees.

Currently, site treatment followed by artificial regeneration is the favoured method. However, on certain sites in which artificial regeneration is going to be difficult, management for existing regeneration may actually be preferable.

6.5.3 Site treatment

Broadcast burning was the most common site treatment applied in the sites sampled. No consistent differences in relative height and planted stocking were observed between burned and unburned sites. In both categories, the best height growth was found on medium and high impacts, with poorest growth on low impacts. All of the 10 best plantations were burned, either intentionally by prescription, or unintentionally, by wildfire.

Mechanical site preparation (MSP) was applied on only two sampled sites. Both were windrowed and both experienced very high site impacts. Consequently, both height growth and stocking suffered.

Mechanical treatments are frequently limited by terrain and poor accessibility in the ESSFa. However, MSP may be a suitable alternative on sites where broadcast burning is not feasible or has failed.

6.5.4 Preparation and planting delays

Preparation delay did not emerge as an important factor affecting regeneration performance. However, average planted stocking levels on burned sites in which preparation delays were greater than 2 years were less than on burned sites experiencing shorter delays.

Planting delays greater than 3 years resulted in reduced relative height growth but not reduced planted stocking. Growth reductions were most pronounced on mesic and wetter sites.

Foresters should attempt to avoid excessive delays on these sites. Poor relative growth should be anticipated when backlog planting mesic and wetter sites. Planting delays on dry sites may not be significant.

6.5.5 Species selection

Incorrect species selection was a problem on a small number of sampled sites. It involved the prescription of spruce on drier sites, especially those receiving high impacts. In such conditions, lodgepole pine is preferable.

Lodgepole pine was only planted on drier and mesic sites. Operational trials involving pine on mesic-subhygric sites with high brush hazard should be undertaken.

Douglas-fir was successful on the few sites in which it was planted. Expanded use of this species on sites less than 1800 m may be worthwhile, subject to pathological constraints.

6.5.6 Stock type and quality

Most plantations contained bareroot stock. The use of early container stock in the 1970's was not without problems, and this was reflected in the poor success rate for these types in this study.

Fall-planted pine stock appeared to suffer high mortality and variable height growth. Plantations established by hot-planted stock were not represented in the sampling.

6.6 Plantation Success

Overall, the Invermere Forest District has enjoyed a higher success rate than the Cranbrook District. Similarly, the Rocky Mountains stand out as being more easily regenerated than the Purcell Mountains. This probably is due to the higher proportion of openings that were treated in the Rockies.

Plantation success was highest at elevations less than 1700 m, on sites receiving medium or high impact broadcast burns, and on mesic sites.

All of the best spruce plantations sustained high or very high site impacts, whereas all of the best pine plantations sustained medium or, in one case, high impacts. A higher proportion of pine plantations sampled were successful than were sampled spruce plantations.

One implication of these results is that to increase overall plantation success, lodgepole pine should be more extensively planted than it was in the historical period studied.

6.7 Problems and Recommendations

This analysis has identified a number of problem areas, related either to site factors or silvicultural factors, which are associated with unacceptably low regeneration performance. These are listed, together with recommendations in this section.

Problem 1. Sites receiving low impact treatments

Statement

This analysis has suggested that site preparation treatments which cause low impact, particularly on mesic and wetter sites, are difficult to regenerate. The problem arises mostly in situations where a prescribed burn failed to achieve target impacts. This failure is frequently due to high duff moisture levels.

Recommendations

The challenge to foresters is to obtain the appropriate site impact consistently across a cutblock. Subhygric sites and steep north aspects in particular should receive high impact treatments. Ways to obtain this objective include the following:

1. Identify areas requiring high duff consumption (at Pre-harvest Prescription stage). Block layout should facilitate high impact burns (e.g., blocks should be as uniform with respect to aspect and moisture regime as possible).
2. Attempt burning of moist sites in drier periods (summer burning), weighing higher control and mop-up costs with greater potential regeneration success.
3. Manage slash so as to maximize burn impact on problem sites; e.g., lopping and topping at the stump, tree-length rather than whole tree logging, thorough slashing etc.
4. Avoid preparation delays on these sites.
5. Apply pre-burn herbicide if preparation delay is greater than 1 or 2 years.
6. Prescribe MSP if burn is impossible or if burn failed to achieve high impact. This is subject to trafficability and terrain limitations.

Problem 2. North aspects are difficult to regenerate

Statement

North aspects, particularly those with slope gradients greater than 20%, are associated with relatively poor height growth and survival. The causes of regeneration difficulty are believed to be primarily abiotic, associated with low soil temperature, short growing season due to delayed snowmelt, temporary moisture excess, and relatively low rates of carbon assimilation due to low growing season air temperatures. However, biotic effects resulting from high levels of competition from either the fireweed or false azalea complex frequently contribute significantly to the problem.

Recommendations

1. Designate steep north aspects as separate, uniform cutblocks as far as possible. Attempt to minimize inclusions of different ecosystems.
2. Try to ensure high impact broadcast burns on these sites. See Problem 1.
3. If successful artificial regeneration is believed to be too difficult, either do not harvest, or manage for advance and residual regeneration.
4. If management for existing regeneration is appropriate (assuming the quantity and quality of regeneration is adequate), an option of relaxing local minimum stocking standards may be necessary. Special amendments to ecosystem-based stocking standards to accommodate partial cutting on steep north aspects should be considered.
5. Slopes over 30% and managed for existing regeneration should be winter logged to minimize damage to soils and advance regeneration. At higher elevations, the potential for avalanching or snowpack damage to residual and downslope stands must be taken into account.

Problem 3. Subhygric and hygric sites

Statement

Wetter sites in this analysis consistently exhibited poor relative height growth or stocking, and frequently both. Wet sites are difficult to regenerate because of a combination of abiotic and biotic factors. Low soil temperature, temporarily saturated conditions, and excessive levels of competition primarily from the fireweed complex conspire to inhibit root extension in the growing season. In addition, cold injury appears to be extensive on these sites. High impact site treatments can partially overcome some of these problems.

Recommendations

1. Attempt to achieve as high a site impact as possible, within ecological tolerances. See Problem 1.
2. Consider clean logging and mechanical site preparation on wet sites that are considered unlikely to sustain high impacts from prescribed fire.
3. Consider mounding treatments such as the Bräcke, Sinkkilä, or spot excavator on appropriate subhygric or hygric sites.
4. Once logged, wetter sites may experience a watertable rise, further complicating regeneration efforts. The potential for this to occur should be explored and recognized as a further difficulty in regeneration.
5. Untreated and imperfectly drained sites may require relaxed stocking and spacing standards if planting is envisaged. Planters should be instructed to select naturally raised microsites such as hummocks or root overturns. Unless a reasonable density of such microsites is available, planting will probably fail.
6. Wet sites that are untreatable should either not be logged, or managed for existing regeneration. In the latter case, the sites should be winter logged. Relaxed stocking standards, as recommended for steep north aspects, could apply. Partial cutting, managed for an acceptable species composition in the residual stand, may be an appropriate option.

Problem 4. Sites above 1800 m

Statement

Plantation success diminishes above 1800 m, primarily because of decreasing survival of planted seedlings. Mortality is probably caused by a short growing season and low average air and soil temperatures. In addition, high elevation sites are frequently located on steep slopes, with shallow, fragmented soils. Thus, moisture stress may be an aggravating factor. Finally, in this analysis, a

larger proportion of openings above 1800 m were created by wildfire (or slashburn escapes) than below this elevation. The site class was frequently low or poor.

Recommendations

1. A lower regeneration success rate above 1800 m should be anticipated. Potentially, the reduced rate may be reflected in modified AAC calculations, regeneration delay and free growing standards. Stocking standards and other ecosystem-based interpretations should be reconsidered for differences above 1800 m.
2. Decreased survival above 1800 m should be recognized by:
   i. increasing target stocking and/or initial planting density on good or medium sites;
   ii. increasing silvicultural effort per planted tree on good or medium sites; and
   iii. decreasing minimum stocking standards, as stated in Recommendation 1.
3. Although the chance of regeneration success is lower at high elevations, it can still be obtained. A greater degree of silvicultural effort may be necessary to ensure that establishing seedlings have all benefits.
4. The use of hot planted stock, planted soon after snowmelt, may be particularly advantageous at higher elevations.

Problem 5. Fireweed-dominated sites

Statement

The fireweed complex may threaten establishing seedlings, particularly on moist (mesic to subhygric) ecosystems which have experienced medium or high impact broadcast burns. The effects of fireweed cover on regeneration performance involve physical damage to young seedlings through snowpress, as well as competition for light, nutrients, and moisture. Fireweed appears to affect survival more than height growth, although it has a deleterious effect on both performance indicators. However, fireweed may act as a nurse crop for slowly growing, naturally establishing spruce seedlings.

The establishment of the fireweed complex can be predicted. There is a trade-off between achieving higher site impacts and tolerating fireweed competition, and prescribing lower impacts with concomitant absence of fireweed competition (although competition from the false azalea complex may be highly significant). This analysis clearly suggests that the former option is superior from the point of view of regeneration performance.

Recommendations

1. Identify sites and treatments that are likely to develop a fireweed complex. These are moist (mesic to subhygric) sites that sustain medium to high broadcast burning impacts. Medium impact sites may contain patchy distributions of pre-logging shrubby species.
2. Prepare for competition from the fireweed complex. This may entail:
   i. prescribing large caliper stock (with high shoot:root ratios);
   ii. planning to avoid planting delays on these sites (this may mean setting priorities among planting projects and allowing a delay on other, less urgent sites;
   iii. considering higher target stocking and/or higher initial planting densities; and
   iv. close monitoring of establishing stands.
3. Consider planting lodgepole pine on certain fireweed-prone sites.
4. A high degree of silvicultural effort should be invested in ensuring successful regeneration on fireweed dominated sites. These are usually productive sites, but if failure ensues, the cost and difficulty of rehabilitation can be very high.
5. Rehabilitation of failed fireweed sites may involve mechanical site preparation (mounding, windrowing, or piling) if terrain and soil allows. The use of prescribed fire is probably limited.

On steep slopes, the use of herbicides, applied aerially or by backpack sprayer, may be an option. Alternatively, light track prime movers, such as the FMC with 6-way blade, can be used to create planting spots. Any light impact treatment may lead to increased cover and vigour of fireweed.

Problem 6. Alder-dominated sites

Statement

Sitka alder can pose a significant threat to established regeneration. In the ESSFa it is present naturally on avalanche paths which serve as seed banks for the colonization of any area containing a suitable seedbed. Alder will grow on most mineral soils in the ESSFa, provided a seed source is available. However, it becomes significant as a competitor only on moist sites which allow prolific growth.

Because it seeds into disturbed sites, it is usually very patchy in distribution and requires between 5 and 10 years to establish. Low levels of alder competition may not harm crop tree growth. In fact, spruce growing amid alder covers up to about 40% estimated cover, showed excellent form and vigour, and moderate height growth (diameter growth was not measured). It is suggested that a threshold of alder competition exists, above which crop tree growth becomes negatively affected.

Recommendations

1. Identify where alder is likely to be a problem. These are moist sites which contain extensive areas of mineral soil exposure, usually resulting from aggressive summer logging and/or mechanical site preparation. Alder establishment may be greater in valleys where slide paths are abundant.
2. Plant promptly with healthy stock on these sites. The use of lodgepole pine, even on moist sites should be considered. Initial height growth may be such that the gradually establishing alder will not be a problem.
3. Stand monitoring and maintenance should be closely observed on these sites.
4. Initiate research into alder-crop tree interaction.

Problem 7. Grass-dominated sites

Statement

The grass complex was frequently encountered in this analysis, particularly in parts of the Rocky Mountains in the Invermere District. It averaged the highest estimated cover on all moisture regimes. However, no effects on survival or stocking were observed. Even very high cover of pinegrass did not seem to affect the growth and survival of lodgepole pine adversely.

This contradicts evidence from adjacent (but drier) parts of the U.S. which suggests that competition for moisture can harm growth and survival of planted conifers (Sloan and Ryker 1986). Perhaps more research is needed on the severity of this problem in the ESSFa.

Recommendations

1. Initiate more research into the interaction between the grass complex and regeneration performance.
2. Where grass has already established, prescribe mechanical site preparation which creates screefed spots (e.g., Bräcke cultivator, Leno, disc trencher). Alternatively, including a screefing clause on planting contracts may be suitable, but this needs to be prescribed on a site-by-site basis.

Problem 8. Sites receiving very high impacts

Statement

Although this analysis has indicated that high impacts are associated with relatively high regeneration success rates, impacts that are too high will have the reverse effect. Very high impacts

may be achieved with poorly executed mechanical site preparation, by wildfires, and by escaped or incorrectly prescribed slashburns.

Skidder logging (in summer) on steep slopes may cause unacceptably high impacts, but on a very discontinuous spatial distribution.

Recommendations

1. More care may be needed in the prescription of mechanical site preparation. Objectives should be kept in mind and these should be communicated to the operator. Excessive impact leading to site degradation appears to be a major concern in windrowing as well as in blade scarification (e.g., dip and dive).
2. Prescriptions should be more carefully made than they have been in the past. Site sensitivity ratings should be properly designed and implemented. A sensitivity rating for mechanical site preparation should be developed, based on soil and terrain factors.

Problem 9. Sites with planting delays greater than 3 years

Statement

Sites which experience a planting delay greater than 3 years are, according to this analysis, associated with a relatively high rate of regeneration failure. This is particularly true on mesic and wetter sites.

In the past, planting delay was primarily due to logistical reasons. These include inadequate seedling supply or supply of requested seedlings, multi-year logging on large openings, or simply the physical inability to plant all openings within a reasonable time. In a large number of openings, natural regeneration failed to meet expectations, and were later planted after a delay of up to 15 years.

Recommendations

1. Avoid planting delays on mesic and wetter sites. If there must be delays, arrange for them to be on drier sites.
2. Take a close look at backlog planting projects on mesic and wetter sites, especially if no further site treatment has been applied. Expectations of performance should be low. The cost and benefit of these projects, relative to other options (such as accepting lower stocking rates or total rehabilitation by knocking down residuals and starting over) must be examined.
3. On mesic and wetter sites in which more than 3 years have elapsed since site preparation, a second treatment should be considered on a site-specific basis.

Problem 10. Untreated sites

Statement

This analysis shows that the low rate of success on untreated sites is a major reason for the high percent NSR land in the ESSFa subzone. The reliance on regeneration in the absence of site treatment in current logging, and the rehabilitation of previously untreated land are the most significant problems facing us today.

Site treatment is not required on all sites. On drier ecosystems, planting may be successful if carried out directly after logging without further treatment. Furthermore, summer logging may create sufficient plantable spots to avert the need for further treatment. On sites in which reliance on established regeneration is appropriate, obviously no treatment needs to be prescribed. In fact, logging on these sites should be scheduled for winter to minimize or avoid ground disturbance. However, a wide range of sites do need to be treated. In the past, they frequently were not.

Recommendations

1. During the pre-harvest silvicultural prescription phase, identify sites which:
   i. require site treatment for successful regeneration; and
   ii. are feasibly treated.
2. Sites which require treatment but which cannot be treated should either:
   i. not be logged; or
   ii. winter-logged and managed for established regeneration if this is deemed to be acceptable (as suggested under Problem 2; local minimum stocking standards may need to be relaxed).
3. Sites in which treatment beyond logging is necessary and feasible should be laid out and planned so as to facilitate the successful execution of that treatment.
4. Untreated sites which are now NSR should be considered in the following decision sequence:

5. The decision to relax local minimum stocking standards should be made on the basis of difficulty and benefit of rehabilitation. For example, sites which may be prohibitively expensive to rehabilitate, or those in which rehabilitation is unlikely to be successful, should be allowed to languish at lower standards. Stands like these must not be allowed to develop from currently logged openings.
6. Planting without treatment is an option which must be very carefully considered, taking into account high cost and low expectation of performance.
7. If treatment is envisaged, options include:
   i. mechanical knockdown of residuals followed by broadcast burning (if fuel constraints permit), or further mechanical treatment (if soil and terrain factors permit);.
   ii. mechanical treatment around and under existing residuals (if this can be done without excessive damage); and
   iii. aerial herbicide application and planting, possibly using a power screefer if terrain prohibits mechanical treatments.

6.8 Research Priorities

Much research is needed both to answer operational questions and to assist foresters in understanding the biological implications of their actions.

A tentative list of the more pressing areas in which research could be carried out follows:

1. Backlog rehabilitation options
2. Mechanical site preparation options
3. Methods for obtaining higher impact slashburns on subhygric sites
4. Performance expectations for Engelmann spruce – Regeneration Performance Assessment (RPA)
5. Micro-environmental constraints
6. Causes of poor growth on low impact or untreated sites
7. Conifer – brush interactions, particularly spruce – alder
8. Species prescriptions and operational trials.

7 REFERENCES

Butt, G. 1987. Regeneration failure and NSR land in the ESSFa subzone: a problem analysis. B.C. Min. For., Res. Sect., Nelson For. Reg., Nelson, B.C. Unpub. rep.

DeLucia, E.H. and W.K. Smith. 1987. Air and soil temperature limitations on photosynthesis in Engelmann spruce during summer. Can. J. For. Res. 17:527-533.

Knapp, A.K. and W.K. Smith. 1981. Factors influencing understory seedling establishment of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) in southeast Wyoming. Can. J. Bot. 60:2753-2761.

Monchak, D.K. 1982. Factors affecting the growth performance and management of subalpine fir advance regeneration in the Kamloops Forest Region. B.C. Min., Silv. Br., Kamloops, B.C. Unpubl. rep.

Shearer, R.C. 1967. Insolation limits initial establishment of western larch seedlings. U.S. Dep. Agric. For. Serv., Ogden, Utah. Res. Note INT-64.

Sloan, J.P. and R.A. Ryker. 1986. Large scalps improve survival and growth of planted conifers in central Idaho. U.S. Dep. Agric. For. Serv., Ogden, Utah. Res. Paper INT-366.

APPENDIX

APPENDIX 1 Summary of sample site data

Opening number	Mountain range	Elevation	Moisture regime	Site preparation	Species planted	Stock type	Impact	Relative height growth	Stocking of planted trees	Total stocking
District C										
Location HARVEY										
G027-16	R	1875	M	B	S		5	3.00	400	1600
G027-16	R	1875	M	B	S		5	3.00	700	3900
G027-16	R	1875	M/SM	B	S		1	1.00	100	600
G027-16	R	1800	SM/M	N			1	2.00	0	500
G027-17	R	1630	SM	B	P		3	4.00	1600	3000
G027-17	R	1630	SM	M	P		5	2.00	1500	2200
G017-17	R	1630	M	B	S		4	3.00	1800	2700
G027-28	R	1500	SM/M	B			4	2.00	0	200
G027-28	R	1500	SM/M	B			5	3.00	0	1100
G027-28	R	1480	M	B	S		5	4.00	1400	2200
G027-28	R	1500	SHG	B	S		4	1.00	700	700
G027-6	R	1900	M	B	S		1	2.00	500	1000
G027-25	R	1700	SM	B	P		3	3.00	700	900
Location CABIN										
G007-22	R	1800	SM	B	S		4	2.00	1100	1300
G017-22	R	1800	M/SM	B	S		1	3.00	0	2800
G007-20	R	1575	SM	N			1	2.00	0	800
G007-20	R	1550	SHG	N			1	1.00	0	200
G017-15	R	1730	SM	B	S		3	3.00	600	1600
G017-15	R	1720	M	N	S		3	4.00	900	1100
G007-3	R	1850	SM	B	S		5	2.00	1700	1800
G007-3	R	1850	M	B	S		1	1.00	1400	2200
G007-3	R	1800	SHG	B	S		5	2.00	200	200
G007-1	R	1625	M/SHG	N	S		4	3.00	1700	3200
G017-42	R	1675	SM	B	S		5	1.00	900	1600
G017-9	R	1725	SM	B	P		4	2.00	600	1300
Location QUINN										
G084-7	R	1524	SM/M	N			1	3.00	0	4800
G034-8	R	1495	SM	N			1	3.00	0	2300
G094-9	R	1615	SM	N	S		5	1.00	900	1200
G094-13	R	1675	SM	N			1	2.00	0	4100
Location BLOOM CREEK										
G003-55	P	1740	M	N	S		4	3.00	1200	1700
G003-55	P	1740	M	N	S	BR2+1	4	3.00	300	1000
G003-55	P	1760	SM/SX	N			5	1.00	0	200
G003-59	P	1620	M	N	S	BR2+0	3	2.00	1700	2300
G003-62	P	1680	SM	N	S		5	2.00	400	500
G003-61	P	1660	M/SM	N	S		5	1.00	1400	1500
G003-61	P	1650	M/SHG	N	S		2	1.00	1000	1500
G003-53	P	1610	SM	N			5	3.00	0	1100
Location WHITE RIVER										
J024-30	R	1750	M	N			1	2.00	0	1000
J024-30	R	1700	M	B	S		4	2.00	400	3800
J024-34	R	1550	SM/M	B	S		5	2.00	1000	1500
J024-34	R	1550	M/SHG	B	S		3	1.00	1000	1800

Opening number	Mountain range	Elevation	Moisture regime	Site preparation	Species planted	Stock type	Impact	Relative height growth	Stocking of planted trees	Total stocking
Location LUSSIER										
G093-84	R	1615	M	M	S	BR2+0	3	2.00	1400	2200
G093-84	R	1600	M	B	S	BR2+0	1	2.00	1700	1800
G093-65	R	1580	M	B	S	BR2+0	1	2.00	1300	1500
G093-65	R	1580	M	B	P	BR2+0	1	2.00	1700	1800
G093-56	R	1780	SM	B	P	BR2+0	3	3.00	1400	1500
G093-51	R	1520	M	B	P		3	4.00	1900	2000
G093-51	R	1500	SM	B	P		4	3.00	1800	1900
G093-63	R	1610	M/SM	B	F		3	4.00	1100	1800
G093-63	R	1620	M	N			1	2.00	0	2300
G093-63	R	1600	SM/SX	B	F		5	1.00	1100	0
Location HORSETHIEF										
K059-6	P	1640	M/SM	B	S	BR1+0	1	1.00	0	0
K059-6	P	1630	M/SM	N	S	BR1+0	0	2.00	900	2600
K059-3	P	1740	M/SM	N	S	BR1+0	1	1.00	900	3300
K059-6	P	1820	M	N	S		1	1.00	1000	1900
K059-11	P	1620	SM	N	F	PSB313-1+0	1	3.00	0	700
Location JUMBO										
K048-10	P	1500	M/SM	B			5	1.00	0	0
K048-10	P	1500	M/SHG	N			1	3.00	0	1200
K048-10	P	1490	M	B			4	3.00	0	2000
K048-10	P	1480	M/SM	N	S		4	3.00	1400	2000
K048-10	P	1480	M	B	S		3	2.00	1700	1800
Location BUGABOOS										
K077-11	P	1640	M/SM	N			2	2.00	0	2700
K077-5	P	1600	SM/M	B			5	2.00	0	1600
K077-5	P	1580	SM	B			5	2.00	0	1500
K077-5	P	1550	M/SHG	B			3	2.00	0	1700